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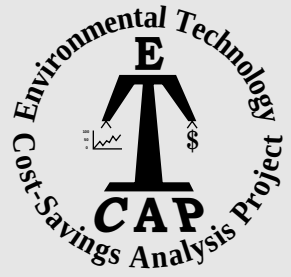

A Compendium of Cost Data for Environmental Remediation Technologies

Los Alamos
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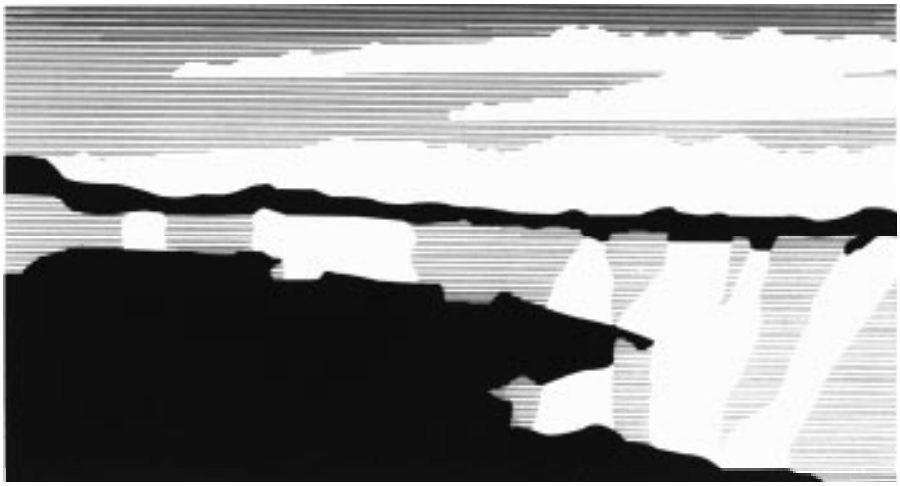

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I. INTRODUCTION

This Compendium provides a representative sample of cost information for environmental remediation technologies used in the treatment of hazardous, radioactive, and mixed waste. Data were gathered from a variety of sources and summarized herein to provide actual cost summaries or engineering cost estimates, site characteristics, and comments detailing remedial projects.

A. Background

Federal, state, and commercial agencies are becoming increasingly involved in environmental restoration activities using both conventional and innovative technologies. In order to evaluate innovative technologies, a comparison of these new technologies to established, or "baseline," technologies is needed.

By using this collection of data, managers and decision makers can access a current compilation of different scenarios to compare costs and performance of remedial actions closely resembling the scale and characteristics of projects under consideration.

This Compendium includes synopses of site characteristics, contaminants, and remedial strategies. Detailed information can be obtained from the cited references. The reader is cautioned that all cost data included are site specific and site experiences are highly variable.

B. Methodology

A comprehensive search was conducted to gather material for this Compendium. Electronic and on-line databases such as the National Technical Information Service (NTIS) database, the Environmental Protection Agency (EPA) National Center for Environmental Publications and Information (NCEPI) Repository, and EPA's Vendor Information System for Innovative Treatment Technologies (VISITT) database were utilized.

Standard published forms of data were also included in the search. Reports cited include EPA Records of Decision (RODs), site characterizations, official remedial action reports, including Remedial Investigation/Feasibility Studies (RI/FS) from Superfund and Department of Energy sites, and progress reports from such agencies as the U. S. Army Corps of Engineers, the Department of Defense, and national laboratories. Reports from the Federal Remediation Technologies Roundtable were included, as were articles from peer-reviewed scientific journals.

To be included as an entry, the data must have been from actual commercial or pilot-scale remedial actions, completed or in progress. As such, neither hypothetical cost scenarios nor cost comparisons were used as the basis for the numbers entered herein. In addition, every effort was made to provide a reasonable synopsis of clean-up activities. In some instances, however, important site information was not available, such as the starting concentration of contaminants, unit costs, or the total volume of material treated. In such cases, the reader is urged to refer to the cited reference.

There has been no attempt to standardize cost categories that were reported in original data. There are several standardized cost reporting/accounting methods available, including the February 1996 Hazardous, Toxic, Radioactive Waste Interagency Cost Engineering Group's *Remedial Action Work Breakdown Structure*. But because the cost information may not have been standardized when collected by the original author, and because the sources do not detail the methods by which costs were reported, all cost data have simply been included herein as were found in the original documentation.

As a special note to investigators, project managers, and contractors: For future data collection and remedial action reporting, it is most helpful when information detailing site activities is as complete as possible. Data should include the kind and total volume of contaminated media, starting concentrations of contaminants, and capital and operating costs. As a guideline for reporting site information, please refer to *Guide to Documenting Cost and Performance for Remediation Projects,* March 1995, EPA/542/B-95/002.

This Compendium contains information obtained from highly-regarded sources. A substantial effort has been made to publish reliable information, but the author nor the Sponsoring Agency can assume responsibility for the validity of all the data or for the consequences of their use.

C. Environmental Technology Cost-Savings Analysis Project

The *Compendium of Cost Data for Environmental Remediation Technologies* has been compiled under the Environmental Technology Cost-Savings Analysis Project (ETCAP) at Los Alamos National Laboratory. ETCAP analyzes potential cost savings that can accrue from successfully implementing innovative environmental technologies. Results of such studies can assist managers in ranking new technologies in terms of cost effectiveness, allocating scarce research and development funding, and recommending which new technologies should undergo implementation for environmental activities. For technical information, contact Steven R. Booth, ETCAP Project Leader, at (505) 667-9422.

D. Sponsoring Agency

This work was supported by the Office of Science and Technology (EM-50) of the U. S. Department of Energy under Technical Task Plan AL-16C501.

E. Disclaimer

Description, reference to, and inclusion of data in this Compendium does not constitute implied endorsement of technologies or vendors. Inclusion of technology descriptions, brand names, and/or trademarked instrumentation, as such, merely helps to detail cost and experience data of environmental activities. For additional information about any of these projects, technologies, or vendors, the reader is encouraged to refer to the cited reference index at the end of each section.

II. OVERVIEW

This overview presents general information regarding the remediation of hazardous, radioactive, and mixed waste. Included are a categorization and brief description of some common remedial technologies, a list of common contaminants, and a list of the abbreviations and acronyms found throughout this publication.

A. Treatment Technologies

Below are some common remedial technologies for soil, sediment, sludge, groundwater and surface water. Technologies are listed by their primary treatment mechanism, (i.e. biological, physical, chemical, or thermal). This is only a representative list. For a complete list, please refer to the Federal Remediation Technologies Roundtable's *Remediation Technologies Screening Matrix and Reference Guide*, EPA/542/B-94/013, from which this list was adapted.

SOIL, SEDIMENT, AND SLUDGE

Biological Treatments Include:

- Bioremediation
- Bioventing
- Composting
- Slurry-Phase Bioremediation
- Solid-Phase Bioremediation
- Surface Biological Treatments

Physical/Chemical Treatments Include:

- Soil Vapor Extraction (SVE)
- Solidification/Stabilization
- Physical Separation/Chemical Extraction
- Soil Washing

Thermal Treatments Include:

- Thermally-Enhanced SVE
- Vitrification
- Thermal Desorption
- Incineration
- Other Treatments including Pyrolysis

Other Treatments Include:

- Excavation

GROUNDWATER & SURFACE WATER

Biological Treatments Include:

- Bioremediation
- Nitrate-Enhanced Bioremediation
- Oxygen-Enhanced Bioremediation
- Bioreactors

Physical/Chemical Treatments Include:

- Groundwater Stripping/Sparging
- Filtration/Separation
- Oxidation
- Pump and Treat with GAC, Thermal Oxidation, Air Stripping, etc.

B. Brief Technology and Term Descriptions

Air Sparging: Injecting air into the saturated zone beneath a contaminated area. As air is injected into the groundwater, gas bubbles form and carry trapped and vaporized contaminants to the unsaturated zone above. Usually used in conjunction with SVE to capture contaminated sparge vapors.

Air Stripping: To remove volatiles dissolved in ground or surface water. Stripping towers (e.g. packed towers) have a concurrent flow of gas and liquid. The evaporative air-waste stream may undergo further treatment in activated carbon, incineration, or other off-gas treatment system.

Biodegradation: Enzyme activity of indigenous soil microbes is stimulated by the addition of aqueous solutions. Further additions of nutrients, oxygen (for aerobic microbes), or other growth factors can expedite contaminant breakdown, and/or contaminant desorption from soil matrix. *In situ* bioremediation includes the promotion of bacterial populations without excavation. *Ex situ* bioremediation works on excavated soils. *Ex situ* systems for contaminated soil or water can also take advantage of aboveground bioreactors which provide an enhanced reaction surface area for enzyme activity.

Bioventing: *In situ* process of injecting air into contaminated soil at an optimal rate, increasing soil O_2 concentration and thereby stimulating the growth of indigenous aerobic bacteria. Low injection rates keep volatilization to a minimum. Effective on organic contaminants, although concomitant use of air extraction may be warranted to capture VOCs. Most effective in the unsaturated zone.

Catalytic Oxidation: A thermal treatment of off-gases where trace organics in the air stream are destroyed. The use of a catalyst (usually a reactive metal) helps to lower the reaction temperature, and thus the energy input.

Chemical Reduction/Oxidation (redox): The addition of ozone (O_3), hydrogen peroxide (H_2O_2), or chlorine compounds induces a redox reaction that chemically converts contaminants into less toxic compounds. This may reduce the mobility of contaminants throughout a plume.

Composting: Contaminated soil is excavated and placed in specialized containers. Cellulose, biomass, nutritional amendments, and sometimes additional indigenous microbes are added to promote breakdown. Specialized bacteria may be added if the aim is to breakdown a particular compound. With proper water content and occasional turning, the contaminants will biodegrade over time.

Dehalogenation: Halogenated volatile organic compounds (VOCs) in excavated soils are dehalogenated using one of two processes. Base-catalyzed dehalogenation involves mixing the soils with sodium hydroxide (NaOH) and a catalyst in a rotary kiln. In glycolate dehalogenation, an alkaline polyethylene glycol (APEG) reagent dehalogenates the VOCs in a batch reactor. The resulting compound from either reaction is non-hazardous or less toxic.

Excavation and Removal: Waste piles, soil, sludge, debris, and/or demolished site structures such as tanks, pipelines, and buildings, are excavated from the site and transported to a permitted waste disposal facility.

Filtration: Contaminated ground or surface water is passed though a porous medium to remove suspended solids. As the water flows through the filter, contaminant solids form a layer on the filter; backflow washing is used to periodically remove this layer. Vacuum filters

B. Brief Technology and Term Descriptions, continued

(Filtration, continued:)

and filter presses may be used for dewatering sludges. This process produces a filter cake which requires disposal.

Free Product Recovery: A method to remove a definable layer of liquid-phase organics (usually petroleum hydrocarbons) from subsurface water formations. Many times accomplished by pumping.

Groundwater Sparging: The combination of promoting (by air injection) natural aerobic biodegradation and removing volatilized contaminants by *in situ* air stripping. Usually for the *in situ* remediation of petroleum hydrocarbons.

Incineration: The combustion of excavated soils and sludges to thermally destroy contaminants. Used in conjunction with an air emissions control system. Often conducted off-site. Rotary kilns incinerate all types of solid and liquid waste and the non-combustible metals and residue are discharged as ash. Fluidized bed incinerators provide a large heat-transfer area for mixing the hazardous waste (usually sludge) and oxygen, producing an inert ash from sludge solids.

In Situ Soil Flushing: Flooding contaminated soil beneath the surface level with a solution designed to flush out the contaminants into a zone from which they will be extracted. Entails the drilling of injection and extraction wells and the addition of acidic or basic solutions, surfactants, or organic solvents to dissolve and remove contaminants. Most effective in soils with low silt and clay concentrations.

Landfarming: Once excavated, contaminated soils are spread over a clean area. The soil is aerated by regular turning or tilling. This speeds the degradation of contaminants.

Membrane Separation: A vapor/air separation involving the diffusion of VOCs though a non-porous gas separation membrane.

Pump and Treat: Refers to pumping contaminated groundwater from an aquifer, and treating the water to remove or destroy the contaminants through one or more processes.

Pyrolysis: Thermal treatment of excavated soils or sludges whereby chemical decomposition is induced in an anaerobic, heated environment. Organic contaminants are volatilized and the remaining solid residue or ash is disposed.

Reactive Barriers: *In situ* method of treating contaminated water by funneling it or enhancing natural flow through a vertically installed physical barrier. This barrier may contain reactive chemicals, metal catalysts (e.g. iron), bacteria, or activated carbon.

Solid-Phase Bioremediation: Excavated soils are placed in lined berms or other above-ground containers, where amendments, nutritional additives, and/or specialized bacteria are added. Solid-phase treatments include treatment beds, biotreatment cells, soil piles, and composting.

Slurry-Phase Bioremediation: An engineered process for treating contaminated soils or sludges that relies upon the mobilization of contaminants to the aqueous phase, where they are susceptible to microbial degradation. Suitable for creosote, petroleum hydrocarbons, and certain chlorinated compounds such as PCBs. The process can take place *ex situ* in bioreactors or *in situ* in lagoons and settling ponds.

B. Brief Technology and Term Descriptions, continued

Soil Vapor Extraction (SVE): To treat VOCs in the unsaturated zone. Vacuum pumping is used to create a zone of low vapor pressure, drawing air through underground wells and causing the *in situ* volatilization of hydrocarbons. SVE is most effective in highly permeable soils.

Soil Washing: An *ex situ* process that uses liquids and pH-controlled chemical additives to scrub excavated soils, thereby removing contaminants and concentrating them for further treatment. Because contaminants often bind to silt or clay, the excavated soils must be sifted and separated, thus reducing the volume of contaminated soil that needs treatment.

Solidification/Stabilization: Used to stabilize or lower the mobility of contaminants. Binding materials or cement react with water and the wastes to produce either a stabilized mass (solidification) or a less-solid material that binds liquids and reduces mobility (stabilization).

Thermal Desorption: Excavated soils and sludges are heated to approximately 800°F (high-temperature thermal desorption) or to approximately 400°F (low-temperature thermal desorption) in an effort to volatilize organic contaminants. An off-gas treatment system is attached to capture and treat vapor-phase contaminants.

Thermally-Enhanced Soil Vapor Extraction: Contaminated soil is warmed either by the injection of hot air or steam, or through the use of electricity or microwave frequencies, thereby volatilizing contaminants. Off-gases are captured in any number of treatment systems.

Ultraviolet (UV) Oxidation: Extracted groundwater is directed toward a treatment tank where UV radiation or ozone (O_3) and/or hydrogen peroxide (H_2O_2) is used to destroy organic contaminants. Off-gases are generally treated with ozonolysis.

Vacuum Extraction: A vacuum created inside a well forces resident groundwater to rise up, allowing additional groundwater to flow in. Once in the well, the air flow causes some of the trapped volatile contaminants to vaporize, thus enabling the capture of VOCs through vapor extraction.

Vapor-Phase Carbon Adsorption: Off-gases collected from a variety of *ex situ* or *in situ* methods are routed through canisters containing granular activated carbon (GAC). Contaminants adsorb onto the carbon, which must be occasionally replaced or recharged.

Vitrification: Mainly used for the remediation of hazardous or radioactive waste. It applies the principle of Joule heating to raise the temperature of soil between an array of electrodes to above the melting temperature. After cooling, a volcanic-like glass is left in the soil's place. For *in situ* application, the resulting non-viscous material has very low potential for leaching. *Ex situ* vitrification applies the same techniques to excavated wastes.

Volume Reduction: Any number of processes that concentrate the contaminated material by separating it from non-contaminated material prior to treatment. Many times organic compounds adsorb to fine soil and clay particles. After separating the large soil and rock fragments, a much smaller volume of contaminated material is left to treat.

C. Contaminant Classifications

Below are common organic and inorganic contaminants found at the sites listed in this Compendium. Compounds are listed by their common name and/or abbreviation. Elemental metals are denoted by their atomic symbols. For a complete listing, the reader should refer to *Remediation Technologies Screening Matrix and Reference Guide*, Second Edition, EPA/542/B-94/013, October 1994.

1. Volatile Organic Compounds

Halogenated VOCs	Nonhalogenated VOCs
carbon tetrachloride (CCl_4)	acetone
tetrachloroethylene	acrolein
perchloroethylene (PCE)	n-butyl alcohol
fluorotrichloromethane (Freon 11)	cyclohexane
1,2-dichloroethane (DCA)	ethyl ether
trichloroethylene (TCE)	BTEX
1,2,2-trifluoroethane (Freon 113)	isobutanol
vinyl chloride	methanol
1,1,1-trichloroethane (TCA)	methyl ethyl ketone (MEK)
	TPH

2. Semivolatile Organic Compounds

Halogenated SVOCs	Nonhalogenated SVOCs	PAHs	Pesticides
pentachlorophenol (PCP)		anthracene	BHC
polychlorinated biphenyls (PCBs)	phthalates	benzo(a)pyrene	DDD
hexachlorobenzene	dibenzofuran	fluorine	DDE
tetrachlorophenol	benzoic acid	naphthalene	DDT
1,2-dichlorobenzene	phenyl naphthalene	pyrene	endrin
dioxins			ethion
furans			malathion
			toxaphene

C. Contaminant Classifications, continued

3. Inorganics

Metals	Radioactive Elements	Others
Al Sb	low level radioactive waste (LLRW)	asbestos
As Be	and	cyanide
Ca Cr	transuranic waste (TRU) including:	fluorine
Cu Fe	Pu-238, -239	alumina
Pb Hg	Ra-224, -226	
Ni Se	Th-228, -230, -232	
Ag Zn	U-234, -235, -238	

4. Explosives

TNT	DNB
RDX	nitroglycerin
HMX	nitrocellulose
TNB	

D. Acronyms and Abbreviations

Acronym	Full Name
BTEX	benzene, toluene, ethylbenzene, xylene
CERCLA	The Comprehensive Environmental Response, Compensation, and Liability Act ("Superfund")
cfm	cubic feet per minute
DCA	dichloroethane
DCE	dichloroethylene
DNAPL	dense non-aqueous phase liquid
DNB	1,3-dinitrobenzene
DOD	U. S. Department of Defense
DOE	U. S. Department of Energy
DRE	destruction and removal efficiency (for thermal treatments)
EPA	U. S. Environmental Protection Agency
ft^2	square foot
gpm	gallons per minute
HMX	high melting explosive ($C_4H_8N_8O_8$)
ISV	in situ vitrification
LLRW	low level radioactive waste
MEK	methyl ethyl ketone
NAPL	non-aqueous phase liquid
NPL	National Priorities List (under CERCLA)
O&M	operation and maintenance activities/costs
PAH(s)	polycyclic aromatic hydrocarbon(s)
PCB(s)	polychlorinated biphenyl(s)
PCE	perchloroethylene, tetrachloroethylene
PCP	pentachlorophenol
ppb	parts per billion (also µg/kg soil; µg/L water)
ppm	parts per million (also mg/kg soil; mg/L water)
RCRA	Resource Conservation and Recovery Act
RDX	research department explosive (cyclonite)
redox	chemical reduction/oxidation reaction
RI/FS	Remedial Investigation/Feasibility Study
ROD	Record of Decision
SITE	Superfund Innovative Technology Evaluation
SVE	soil vapor extraction
SVOC(s)	semivolatile organic compound(s)
TCA	1,1,1-trichloroethane
TCE	trichloroethylene
TCLP	toxicity characteristic leaching procedure
THC	total hydrocarbons
TNT	2,4,6-trinitrotoluene
TPH	total petroleum hydrocarbons
TRU	transuranic waste
TSS	total suspended solids
USACE	U. S. Army Corps of Engineers
UST	underground storage tank
UV	ultraviolet radiation
VOC(s)	volatile organic compound(s)
XRF	x-ray fluorescence
yd^3	cubic yard

E. Cost Terminology*

In general, costs are site-specific and based on parameters such as the type of remediation technology selected, the size of the affected area, the characteristics of the contaminants, the required clean-up standards, the level of health and safety protection during the remediation, the type and number of chemical analyses, and any long-term, post-remedial actions required.

Costs can generally be broken down into *capital costs* and *operating costs*.

Capital Costs:

- usually (but not always) constitute one-time costs that occur at the beginning of a project
- installed equipment such as off-gas treatment equipment, tanks, pumps, blowers, above-ground drainage, containment structures, air or water monitoring equipment
- constructed buildings and structures such as on-site labs, health and safety offices, and monitoring facilities
- costs involved with design, engineering, start-up, site preparation, well drilling, and mobilization/demobilization
- total capital costs are the sum of the equipment and installation costs

Operating Costs:

- associated with actually doing the work necessary to obtain the required remediation levels, and are recurring
- sometimes referred to as "Annual Operating Costs" or "O & M"
- these costs include labor, utilities, sampling and analysis, consumables, equipment repair and maintenance, disposal and transportation, project management, quality assurance measures, insurance, and leases

Total costs for a full-scale remediation are found by adding the capital, operating, and any contingency costs associated with unforeseen difficulties. Cost per gallon, cubic yard, or ton can be calculated by dividing the total cost of a full-scale remediation by the volume of material treated or the volume of contaminant removed. Generally, as the volume of material increases, the cost of the remediation decreases due to economy of scale.

Please Note: When a unit cost was not available in the original source, although a total treatment cost and a total volume of contaminated media were given, the author proceeded to calculate the unit cost. This number, if not from the original data, is given in italics in the "Cost" category. Please see example on following page.

* Adapted from Henrikson, Anne D. and Steven R. Booth, "A Practical Guide to Evaluating the Cost Effectiveness of New Environmental Technologies," Los Alamos National Laboratory report LA-UR-93-4485 (1993).

F. Entry Example

Treatment Technology	Cost Elements	Cost	Site Characteristics/Comments	Ref.
Pump and treat å	Total capital costs (site prep, system installation, start-up, demolition, excavation, mobilization) Annual operating costs (equipment, labor, materials,) ç	$569,739 $216,561 *($0.10/gal.)* é	Langley Air Force Base, Aviation R&D Facility, Virginia Media: 2,000,000 gal. H_2O Contaminants: BTEX; TPH >100 ppm in soil, max. 4100 ppb in groundwater; free product Details: UST site with 24 25,000 gallon tanks; Full-scale remediation of fuel oil-contaminated groundwater using vacuum assisted well-point extraction and aboveground air stripping; Pump and treat with vacuum-assisted well point extraction system, oil/H_2O separators, air strippers; Avg. 32 gpm flow rate; 2 air stripper columns è	15, (1995) ê

1. **Treatment Technology:** Refers to the technology chosen to remediate a site. Often times projects will list two technologies selected for a site. As appropriate, such entries will be listed under all applicable technology categories.

2, 3. **Cost Elements and Cost:** Describes and lists the costs as reported in the original data source. In some cases, a single *"Total treatment cost"* is reported, indicating that the actual cost of remediating the site, regardless of the number of technologies used or the volume or type of contaminants, is all inclusive. *"Total cost/unit"* refers to the total cost of remediating the site divided by the total volume of material treated (e.g., cubic yards of soil) or the total contaminant volume removed (e.g., pounds of VOCs incinerated). This number will be in italics if calculated by the author rather than found in the original report.

   When available, specific capital and operating costs have been listed. In addition, costs based on throughput of the system or volume treated (e.g., gallons per minute), if affecting overall cost, are also listed. In many cases, additional specifics about cost can be found in "Site Characteristics/Comments."

4. **Site Characteristics/Comments:** Lists site name and location, type and volume of medium if known, and the contaminants found at the site. In some instances only a general description of media and contaminants was available. "Details" refers to remedial action details, and may list the achieved contaminant level, plume characteristics, details of the treatment system, and specifics of how cost data were derived.

5. **References:** Each entry is referenced. The numbers, with the year of publication, correspond to the cited reference list found at the back of each section.

A. SOIL, SEDIMENT, AND SLUDGE

1. BIOLOGICAL TREATMENTS

A. SOIL, SEDIMENT, AND SLUDGE

1.a. BIOLOGICAL TREATMENTS: *IN SITU*

BIOVENTING

Treatment Technology	Cost Elements	Cost	Site Characteristics/Comments	Reference
Bioventing	Total capital cost	$150,000	US DOE Savannah River Site, Aiken, South Carolina Media: soil and groundwater Contaminants: primarily TCE, PCE; soil contamination was 10 ppm; groundwater contamination was 1 ppm Details: Contamination from solvents used to degrease nuclear fuel target elements; Remediated to < 2 ppb; Used 200 man hours/wk.	1, (1994)
Bioventing	Total cost/unit	$10 to $15/yd^3	Hill Air Force Base, Utah Media: soil contaminated to a depth of 60 ft. Contaminants: TPH at 20,000 ppm Details: Spill contained 25,000 gallons JP-4 jet fuel; 98% reduction in contaminants; Min. and max. bioventing costs reported	2, (1994)
Thermally-enhanced bioventing	Capital cost (floating fuel collection devices, bioventing equipment, composting, site mobilization/ demobilization, groundwater remediation) Annual O&M (floating fuel treatment for 5 yrs., bioventing for 10 yrs., groundwater monitoring for 30 yrs.) Total cost/unit	$758,077 $177,160/yr. (1994) $10 to 15/yd^3	Refueling Loop E-7, Source Area ST20, Eielson Air Force Base, Fairbanks, Alaska Media: soil (contamination to 6.1 m in saturated zone) Contaminants: TPH, BTEX; soil contained avg. 1500 mg/kg TPH Details: **Pilot scale**; JP-4 jet fuel spill; Contamination was concentrated below 5.25 ft.; Bioventing with 3 soil-warming techniques: Active warming, passive warming, and surface warming; Clean-up level is 200 mg/kg TPH; Min. and max. bioventing costs reported	3, (1995)

A. SOIL, SEDIMENT, AND SLUDGE				
1.a. BIOLOGICAL TREATMENTS: *IN SITU*				
BIOVENTING, continued				
Bioventing	Total capital cost (equipment, site work, engineering, project mang.) Annual operating cost (electricity, lab, maintenance)	$28,650 $32,875/yr. (1994)	UST Site, Lowry Air Force Base, Denver, Colorado Media: soil; no quantity estimate at time reference was published Contaminants: TPH at 15 to 14,000 mg/kg; BTEX Details: Bioventing with 6 piping manifolds placed at right angles in excavation area (35 to 40 ft. deep); Aerated to maintain O_2 conc. >14%; Clean-up levels are < 500 mg/kg TPH; Key operating and cost parameters were soil moisture, O_2 and CO_2 concentrations	4, (1995)
Bioventing with SVE	Capital cost (construction and start-up) Operation cost (electricity, fuel, labor, lab, equipment leases for 2 yr. operation) Total treatment cost	$335,000 $132,000/yr. (1990) $599,000 *($120/yd^3)*	JP-4 Fuel Spill Site at Site 914, Hill Air Force Base, Ogden, Utah Media: 5000 yd^3 soil, 13,500 ft^2 area Contaminants: 27,000 gal. JP-4 jet fuel; TPH from 20 to 10,000 ppm, avg. 400 ppm Details: Two-phase clean-up: Phase 1 - SVE with 7 vent wells (50 ft.); 31 monitoring wells (6 to 55 ft.); 3 neutron access probes to monitor soil moisture; Catalytic incinerator for extracted vapor; Phase 2 - bioventing to reduce soil TPH levels to clean-up goals; Bioventing for 15 mos.; 4 vent wells and the monitoring wells from SVE	5, (1995)
Low intensity bioventing	Total capital (construction, buildings, start-up - estimate) Total operating cost (labor, utilities, lab, maintenance, monitoring; estimated over 4 yrs.)	$115,000 $24,000/yr. (1994)	Hill Air Force Base, Site 280, Ogden, Utah Media: soil Contaminants: TPH and BTEX; soil TPH as high as 5040 ppm in soil Details: Bioventing system included one injection well at 100 ft. and 10 monitoring wells at varying depths; Low intensity bioventing system in place since Dec. 1990	6, (1995)

A. SOIL, SEDIMENT, AND SLUDGE				
1.a. BIOLOGICAL TREATMENTS: *IN SITU*				
BIOVENTING, continued				
Bioventing	Total cost/unit	$15 to $20/$m^3$ ($12 to $15/$yd^3$)	Tyndall Air Force Base, Florida Media: soil in vadose zone Contaminants: TPH >1000 mg/kg soil Details: **Pilot scale field test**; Volatile hydrocarbons in vadose zone; Remediated to < 30 mg/kg; Min. and max. costs of bioventing listed in case study	7, (1994)

A. SOIL, SEDIMENT, AND SLUDGE

1.a. BIOLOGICAL TREATMENTS: *IN SITU*

IN SITU BIOREMEDIATION

Treatment Technology	Cost Elements	Cost	Site Characteristics/Comments	Reference
In situ bioremediation	Total treatment cost (including subcontractor)	$50,000 *($13/yd^3)*	Biota Division of CET Environmental Services, California Media: 4000 yd^3 soil Contaminants: TPH from 1200 ppm to 45,000 ppm; highest concentration at 20 ft. below surface Details: Remediation of an industrial bottling plant and truck garage containing USTs and fuel pumps; Action included initial biotreatability investigation, bench-scale assessment, and on-site field implementation	8, (1994)
In situ bioremediation	Total cost/unit (including comprehensive biotreatability investigation, pilot-scale test, and full-scale treatment)	$145/yd^3	Biota Division of CET Environmental Services, Arizona Media: 1600 yd^3 soil over a one acre area Contaminants: up to 38,000 ppm butyl benzyl phthalate Details: Train derailment site; Reduced phthalate to an average level of >90 ppm	9, (1994)
In situ bioremediation	Total treatment cost	$274,000 (1990)	New York State Department of Conservation UST Site Media: soil, groundwater Contaminants: 10 ppm BTEX in groundwater Details: Leaking UST; 6 monitoring wells installed to track movement of plume; Infiltration gallery constructed at former UST location to flush hydrocarbons out of aquifer; Nutrients and H_2O_2 added to promote in situ biodegradation; Remediated to below detect	10, (1994)

A. SOIL, SEDIMENT, AND SLUDGE				
1.a. BIOLOGICAL TREATMENTS: *IN SITU*				
IN SITU BIOREMEDIATION, continued				
In situ bioremediation	Treatment cost/unit (includes capital and pre-treatment; does not include site prep, excavation, waste handling, residual disposal, or permitting)	$31.25/1000 gal.	West Wago, Louisiana Media: 4 million gallons sludge and process water Contaminants: 20,000 ppm oil and grease Details: One acre lagoon with 75% surface area covered with waxy sludge; Biodegradation in two phases: one for sludge with surface aerators, and the second for emulsified oil in process water; Remediated to >15 ppm oil and grease	11, (1994)
In situ bioremediation and off-site landfarming	Total treatment cost	$250,000 (1989)	Chevron Site, Plaquemine Parish, Louisiana Media: two waste pits containing a total of 2800 yd^3 of oily solids/sludge; 2050 barrels of floating hydrocarbons Contaminants: oil and grease, paraffin, nonsoluble organics Details: 1200 barrels of soluble oil recovered by skimming, chemical coagulation, and oil separation; 850 barrels of waste oil were landfarmed at a separate facility; Liquid/solid contact bioremediation; Volume reduction on remaining contaminants with commercial cultures and concurrent stimulation of indigenous microbes; Free liquid discharged; Remaining material was stabilized and pit was backfilled	12, (1994)
In situ bioremediation	Total treatment cost (including installation, equipment, analytical, operations, and labor)	$110,000 *($1/gal.)*	EPA Region 1 Demonstration Site, Massachusetts Media: 135,000 gallons groundwater Contaminants: 2 ppm each TCE and DCE Details: **Pilot scale**; Amended groundwater with O_2, CH_4, and mineral nutrients, recirculating water through contaminated area; Demonstration ran for 15 months with 25% reduction in both TCE and DCE	13, (1994)

A. SOIL, SEDIMENT, AND SLUDGE				
1.a. BIOLOGICAL TREATMENTS: *IN SITU*				
IN SITU BIOREMEDIATION, continued				
In situ bioremediation	Total cost/unit	$25/yd^3	Former Petroleum Products Storage and Distribution Facility, New York Media: 27,000 yd^3 soil Contaminants: max. conc.: 13,072 ppm methanol, 1830 ppm N,N-dimethylaniline, 883 ppm acetone, 827 ppm methylene chloride, 140 ppm TCE, 218 ppm xylenes, 11 ppm benzene Details: 90-day bench scale treatability study followed by pilot study in 8000 ft^2 area; Full-scale treatment used tilling for top 18 in. and deep auger mixing down to 6 ft.; Nitrate and phosphate amendments at deeper depths; Soil gas and ambient air monitoring; Soil mixing took place 5 days/wk., soil moisture maintained between 50% and 75%; 8 mo. remediation	14, (1996)
In situ bioremediation plus bioreactor treatment of groundwater	Total project cost	$91,700	Naval Air Warfare Center, Lakehurst, New Jersey Media: soil below lagoon; groundwater in 8100 ft^2 contaminant plume Contaminants: ethylene glycol: max. conc. in soil 4900 ppm, max. conc. in groundwater 2100 ppm Details: First phase used injection system for in situ biodegradation by adjusting pH and providing O_2 and nitrogen/phosphate amendments; 5 recovery wells pumped contaminated groundwater into bioreactor; Reinjection into vadose zone after treatment; Avg. flow rate in closed loop of 20 gpm; Lagoon injection system flushed contaminated soil and forced contaminated water to 1 of 3 recovery wells in lagoon; 435 day treatment lowered contaminants to non-detect levels	15, (1994)

A. SOIL, SEDIMENT, AND SLUDGE				
1.a. BIOLOGICAL TREATMENTS: *IN SITU*				
IN SITU BIOREMEDIATION, continued				
In situ bioremediation, incineration, and pump and treat	Bioremediation, excavation, and incineration: Capital costs O&M Present worth Pump and treat: Capital costs O&M Present worth	 $29 million $500,000/yr. $40 million (1993) $2 million $250,000/yr. $6 million (1993)	American Creosote Works Inc. Site, Winnfield, Louisiana Media: 25,000 yd^3 sludge, 250,000 yd^3 soil, shallow groundwater Contaminants: PAHs, PCP Details: Excavation and incineration of 25,000 yd^3 highly contaminated sludge and tars; Decontaminated ash used on-site as fill; Pump and separate NAPLs from sub-surface zones of pooled product to promote biodegradation of PCP and PAHs; Incineration of NAPLs and reinjection of water to promote flushing of contaminants into 250,000 yd^3 in situ biotreatment zone; O_2 and nutrients added; 30 yr. remediation	16, (1993)
In situ bioremediation and pump and treat	Capital: Soil treatment Groundwater treatment Site overhead O&M Replacement costs Present worth	 $1,475,000 $971,000 $1,764,000 $0 $0 $4,210,000 (1988)	North Cavalcade Street Site, North Cavalcade, Texas Media: 22,300 yd^3 soil, 5.6 mil. gal. groundwater Contaminants: max. H_2O conc.: 79 µg/L benzene, 620 µg/L toluene, 280 µg/L xylenes, 39,000 µg/L naphthalene; max. soil conc.: 14,394 ppm total PAHs, 9187 ppm naphthalene Details: Clean-up levels are 1 ppm for carcinogenic PAHs in soil and 5 µg/L in groundwater; In situ bioremediation of soils with O_2 and nutrients, 3 yr. duration; On-site pump and treat with oil/H_2O separation and carbon filtration to be completed in 2 yrs.; This remedy has no long-term O&M costs beyond 5 yrs. according to ROD and no replacement costs because of no long-term operation	17, (1988)
In situ bioremediation	Total treatment cost (including analytical program and biological site assessment)	$118/$yd^3$ (1990)	Ashland Petroleum, Pennsylvania Media: 15,000 yd^3 soil Contaminants: 12,000 ppm diesel Details: Remediated to 450 ppm avg. across site	18, (1994)

A. SOIL, SEDIMENT, AND SLUDGE				
1.a. BIOLOGICAL TREATMENTS: *IN SITU*				
SOLID-PHASE BIOLOGICAL TREATMENT				
Treatment Technology	**Cost Elements**	**Cost**	**Site Characteristics/Comments**	**Reference**
Enhanced in situ solid-phase biological treatment	Total treatment cost	$300,000 *($200/yd^3)*	CONRAIL Train Derailment Site, Mentor, Ohio Media: 1500 yd^3 (1100m^3) soil; 200 ft^2 swampy area to a depth of 1 ft. Contaminants: 12,000 gallons vinyl acetate; 22,000 mg/kg acetate; 3000 mg/kg acetaldehyde Details: Recovered 6000 gal. product; Incomplete oxidation products ethanol and acetate treated to < 2.5 mg/kg and 12 to 15 mg/kg, respectively	19, (1996)

A. SOIL, SEDIMENT, AND SLUDGE

1.b. BIOLOGICAL TREATMENTS: *EX SITU*

COMPOSTING

Treatment Technology	Cost Elements	Cost	Site Characteristics/Comments	Reference
Windrow composting	Capital cost (equipment, buildings, structures, mechanical/ piping, electrical) Operating cost (power, amendments, fuel, labor, maintenance) Total cost/unit	$1,840,000 $527,000/yr. (1992) $450/yd^3	Explosives Contaminated Site, Umatilla Army Depot Activity, Hermiston, Oregon Media: approx. 20,000 tons soil below 2 settling lagoons to 5 ft. depth Contaminants: TNT up to 1600 ppm, RDX up to 1000 ppm, HMX up to 200 ppm Details: Costs do not reflect treatment of 244 yd^3 soil in previous 40 day field demo; Operating costs assume 20,000 tons and a 5 yr. remedial duration	20, (1995)

A. SOIL, SEDIMENT, AND SLUDGE

1.b. BIOLOGICAL TREATMENTS: *EX SITU*

SOLID-PHASE BIODEGRADATION/ LAND TREATMENT

Treatment Technology	Cost Elements	Cost	Site Characteristics/Comments	Reference
Solid-phase biodegradation	Total treatment cost	$500,000 (1990) *($30/yd^3)*	Bay Area Refinery, Rodeo, California Media: 16,000 yd^3 soil Contaminants: diesel, waste oil Details: Major obstacles were clayey soils and unexpected long-chained hydrocarbons; Remediated to 100 mg/kg diesel and 100 mg/kg waste oil	21, (1994)
Solid-phase biodegradation	Total treatment cost (ROD estimate)	$2,275,000 *($100/yd^3)*	American Creosote Works Site, Pensacola, Florida Media: 23,000 yd^3 soil Contaminants: dioxins, carcinogenic PAHs, PCPs Details: 18 acre site; Surface impoundment ponds with oily, asphaltic, creosote material; Ponds were dewatered and water treated and discharged into city sewer system; Sludge in ponds was solidified and capped; Excavation and treatment of 23,000 yd^3 PAH-contaminated soil using solid-phase biodegradation; Disposal of treated soil on-site in excavated area with backfilling	22, (1995)
Controlled solid-phase biodegradation	Total cost/unit	$36/m^3 ($27/yd^3)	Marine Corps Air Ground Combat Center, Twenty-Nine Palms, California Media: soils Contaminants: TPH, avg. 702 ppm Details: **Heap pile research project**; Contamination from UST and fuel spills; Remediated to 234 ppm avg.	23, (1994)

A. SOIL, SEDIMENT, AND SLUDGE				
1.b. BIOLOGICAL TREATMENTS: *EX SITU*				
SOLID-PHASE BIODEGRADATION/LAND TREATMENT, continued				
Controlled solid-phase biodegradation	Total cost/unit	$88/metric ton ($80/ton)	Marine Corps Mountain Warfare Training Center, Bridgeport, California Media: soils Contaminants: 1200 ppm TPH Details: **Pilot study** at UST site; Aerated soil pile on lined bed; Remediated to 120 ppm after 2 mos.	24, (1994)
Solid-phase biodegradation	Total cost/unit	$20/$yd^3$ ($26/$m^3$)	Sand and Gravel Mining Location, Ventura County, California Media: 58,200 yd^3 soil Contaminants: BTEX, gasoline; TPHC ranged from 74 to 41,000 mg/kg Details: Soil tilled to 18 in. depth; Tilled once every 2 weeks and after amendments (ammonium sulfate and diammonium phosphate) were added; Soil moisture content was between 60 and 80%; Treatment area divided into 32 plots, approx. 1 acre each; Excavation took 44 days; BTEX and gasoline concentrations were below detect after treatment (1 and 5 mg/kg, respectively)	25, (1994)
Solid-phase biodegradation	Total treatment cost (expected)	$8.3 million *($200/yd^3)*	Ordnance Works Disposal Area Superfund Site, Operable Unit 1, West Virginia Media: 42,000 yd^3 soil Contaminants: carcinogenic PAHs Details: Solid-phase biodegradation of soil contaminated with PAHs; Ex situ solidification used for any inorganics found in soil after biological treatment; Target level is 44.7 ppm carcinogenic PAHs	26, (1991)

A. SOIL, SEDIMENT, AND SLUDGE

1.b. BIOLOGICAL TREATMENTS: *EX SITU*

SOLID-PHASE BIODEGRADATION/LAND TREATMENT, continued

Treatment Technology	Cost Elements	Cost	Site Characteristics/Comments	Reference
Solid-phase biodegradation plus in situ bioremediation of groundwater	Total treatment cost	$11 million	Burlington Northern Railroad Superfund Site, Somers, Montana Media: groundwater; 12,000 yd^3 excavated soil; 70,000 yd^3 soil in situ Contaminants: PAHs, zinc, and phenol in soil, PAHs in groundwater Details: Operational early 1993 with 5 to 10 yr. completion time; 12,000 yd^3 excavated soil undergoing solid-phase biodegradation; Groundwater being treated with in situ bioremediation; Soil concentration target is 36 μg/kg PAHs and groundwater target is 0.030 μg/L PAHs; Soil also treated with in situ soil flushing	27, (1991)
Solid-phase biodegradation	Total treatment cost (expected)	$23.5 million *($200/yd^3)*	Amoco Refinery, Sugar Creek, Missouri Media: 137,000 yd^3 soil and sludge Contaminants: oil, PAHs, refinery sludges, metals; soils and sludge contain 27% to 40% oil and grease Details: Full-scale remediation began July 1990 with expected completion in 1999; Sludges contain high concentrations of K049, K050, and K051 oil; Soils and sludge undergoing solid-phase bioremediation in sequencing batch reactors; Target clean-up levels are total PAHs < 300 mg/kg and carcinogenic PAHs <1 60 mg/kg	28, (1991)

A. SOIL, SEDIMENT, AND SLUDGE				
1.b. BIOLOGICAL TREATMENTS: *EX SITU*				
SOLID-PHASE BIODEGRADATION/LAND TREATMENT, continued				
Land treatment	Total cost (solids prep, handling, mobilization, short-term and long-term O&M) Pre-treatment costs (site work, containment) After-treatment costs	$600,000 $58,000 $9800	Brown Wood Preserving Site, Live Oak, Florida Media: 12,000 yd^3 soil Contaminants: creosote (total PAHs 100 to 209 mg/kg) Details: Land treatment system included installation of clay liner, berm, subsurface drainage system, and retention pond; Soil treatment using three lifts, the first inoculated with PAH-degrading bacteria	29, (1995)
Land treatment	Capital cost (site work, permitting, construction, mobilization/ demob., project mang., and pilot test [$76,000 of total capital costs]) Operating cost (lab, maintenance, and monitoring - estimate)	$104,257 $18,460/yr.	UST Site, Lowry Air Force Base, Denver, Colorado Media: 5400 yd^3 soil plus three truckloads Contaminants: TPH and BTEX from leaking heating oil tank; estimated 10,500 gallons fuel oil released; BTEX at 100 mg/kg; Total recoverable petroleum hydrocarbons (TRPH) up to 11,000 ppm, avg. 3100 ppm Details: USTs removed and contaminated soil was excavated; Land treatment of excavated soils consisted of adding ammonium nitrate and tilling twice a month; Soil moisture content was kept at 10 to 15% by weight; Target clean-up level is <500 ppm for TPH and TRPH	30, (1995)
Land treatment	Total Removal Action Land treatment contractor Lab analysis, EPA contractors, and EPA oversight	$4,047,000 (1991) $1,292,000 $254,000	Scott Lumber Company Superfund Site, Alton, Missouri Media: 15,961 tons soil; sludge, surface debris, and lagoon wastes Contaminants: creosote/diesel fuel mixture; PAHs as high as 63,000 mg/kg in soil, 0.326 mg/kg in lagoon, and 12,400 mg/kg in sludge Details: Three operable units: Decontamination and removal of surface debris and sludge; Excavation of contaminated soil; On-site land treatment; Site demobilization in Sept. 1991	31, (1995)

A. SOIL, SEDIMENT, AND SLUDGE				
1.b. BIOLOGICAL TREATMENTS: *EX SITU*				
SOLID-PHASE BIODEGRADATION/LAND TREATMENT, continued				
Land treatment and oxygen-enhanced water treatment	Total remediation cost (including pilot and full-scale operations)	$8 to $10 million	Libby Groundwater Superfund Site, Libby, Montana Media: screened soil and rock totaling 75,800 yd^3; groundwater plume extending approx. 1 mile Contaminants: total concentration of creosote and PCP >5000 mg/kg Details: Used 4 existing monitoring wells; H_2O_2 injection system with new monitoring and extraction wells drilled; Groundwater recovery with 2 fixed-film bioreactors; 2 land treatment units for contaminated soil, each 1 acre in size with a capacity of 25,000 yd^3; 6 yr. operational period for soil and < 10 yrs. for aquifer treatment to obtain target concentrations of >100 mg/kg	32, (1994)
Land treatment	Total cost/unit	$351/$yd^3$ (1991)	Navy Demonstration, Camp Pendelton, California Media: soil Contaminants: TPH at 29,000 ppm Details: **Field demonstration**; Excavated soil was tilled at surface after weekly nutrient/enzyme additions; 50 yd^3/mo. capacity; No residual waste produced; TPH remediated to 88 ppm; No future O&M costs associated with remedy	33, (1994)
Land treatment plus fixed film bioreactor treatment of water	Total treatment cost (expected)	$3.5 million	JH Baxter Superfund Site, Weed, California Media: groundwater; 21,875 yd^3 soil Contaminants: As, Cr, Zn, PCP, PAHs, dioxins/furans Details: Organic-contaminated soil (12,500 yd^3) treated in prepared-bed land treatment unit; Soil with mixed organic and heavy metal contamination needs further treatment; Groundwater pumped and treated in fixed film bioreactor; Start-up March 1993	34, (1991)

A. SOIL, SEDIMENT, AND SLUDGE				
1.b. BIOLOGICAL TREATMENTS: *EX SITU*				
SOLID-PHASE BIODEGRADATION/LAND TREATMENT, continued				
Land treatment	Capital costs O&M Present worth (ROD estimate)	$2.2 million $195,000/yr. $2.47 million (1991)	South Andover Salvage Yards Superfund Site, Operable Unit 3, Andover, Minnesota Media: 11,400 yd^3 soil; 20 waste drums Contaminants: max. PAHs 30.3 ppm; max. Pb 1980 ppm; max. PCB 15.17 ppm; max. Sb 75.9 ppm Details: Characteristic hot spot contamination confined to upper 6 ft. of surface soils; Excavation of 2100 yd^3 PAH-contaminated soil for surface biological treatment; Excavation of 9300 yd^3 mixed organic- and metal-contaminated soil for off-site disposal; Sampling and removal of 20 waste drums; Backfilled site with treated soil and clean fill; Semi-annual monitoring and run-off control measures; 2 yr. remedial period	35, (1991)
Land treatment of soil plus pump and treat with incineration	Biological treatment: Capital costs O&M Present worth Pump and treat: Capital costs O&M Present worth	 $11.5 million $25,000/yr. $11.9 million (1992) $1.2 million $153,000/yr. $5.3 million (1992)	Popile Inc. Site, El Dorado, Arkansas Media: 165,000 yd^3 soil and sludge; 84 mil. gal. groundwater; 750,000 gal. pooled creosote Contaminants: up to 32,700 ppb benzo(a)pyrene and up to 280,000 ppb PCP in soil; up to 698 ppb benzo(a)pyrene equivalent and 460,000 ppb PCP in groundwater Details: Excavation and treatment of 165,000 yd^3 soil and sludge in on-site biological land treatment unit with 15 to 20 yr. treatment time; Extraction wells, interceptor trenches, and subsurface drains to capture pooled product and create hydraulic containment barrier; Partial slurry wall to prevent infiltration of surface water to groundwater; Removal of NAPLs with sedimentation and oil/H_2O separation; Filtration of water in sand filter and activated carbon; Reinjection followed by possible deep in situ bioremediation with injection wells and feed system for unrecoverable NAPLs; Last phase will cost an additional $950,000	36, (1993)

A. SOIL, SEDIMENT, AND SLUDGE				
1.b. BIOLOGICAL TREATMENTS: *EX SITU*				
SOLID-PHASE BIODEGRADATION/LAND TREATMENT, continued				
Land treatment of soil with incineration and pump and treat with GAC	Total Capital O&M Present worth (7% discount rate, 30 yr. duration, ROD estimate)	$12,050,000 to $20,250,000 $657,000 to $4,420,000/yr. $27,530,000 to $55,200,000 (1993)	Montana Pole and Treating Plant Superfund Site, Butte, Montana Media: 218,000 yd^3 excavated soil; 44,000 yd^3 soil in situ; 26,500 gal. sludge; 9100 yd^3 debris; 90 mil. gal. groundwater Contaminants: max. conc.: 1160 mg/kg PCP; 2304 mg/kg PAHs; 55.6 mg/kg TPH; plus 370,000 gal. LNAPLs Details: Excavation of 208,000 yd^3 contaminated soil added to 10,000 yd^3 excavated soil stored on-site; Treatment in land treatment unit; Estimated 7 yr. duration; In situ biodegradation of soils below excavation level before backfilling; Soil flushing and bioremediation of inaccessible soils; Containment/ hydraulic barrier installation; Pump and treat of groundwater with oil/H_2O separation and GAC plus UV oxidation; Estimated 30 yr. duration; Discharge and reinjection of treated water to enhance in situ bioremediation of contaminated groundwater and soils; Decontamination and off-site disposal of debris; Excavation, transportation, incineration of sludge off-site; Long-term groundwater monitoring	37, (1993)

A. SOIL, SEDIMENT, AND SLUDGE

1.b. BIOLOGICAL TREATMENTS: *EX SITU*

SOLID-PHASE BIODEGRADATION/LAND TREATMENT, continued

Land treatment of soil with bioventing, chemical fixation, and pump and treat with GAC	Total O&M Capital costs: Soil remedy Groundwater remedy Debris remedy Indirect and contingency Present worth (ROD estimate)	$7,400,185 $1,718,402 $2,757,039 $949,776 $1,253,977 $15,551,033 (1992)	Broderick Wood Products Superfund Site, Operable Unit 2, Adams County, Colorado Media: 59,000 yd^3 organic-contaminated soil; 120 yd^3 sediments; 800 yd^3 metal-contaminated soil; 526 mil. gal. groundwater; 42,000 yd^3 sludge; 850 yd^3 debris Contaminants: max. in soil: 14,000 ppm PAHs, 8600 ppm PCPs, 0.38 ppm benzene, 21.4 ppm xylenes, 56 ppm dioxins/furans Details: 59,120 yd^3 soil and sediments excavated and biodegraded in land treatment unit; 800 yd^3 heavy metal-contaminated soil treated by ex situ chemical fixation and disposed of in off-site permitted facility; Extracted groundwater sent through oil/H_2O separator, treated in clay and GAC, reinjected into shallow aquifer; Bioventing of deep contaminants; 25 monitoring wells installed; Soil/bentonite wall plus drainage ditch linings installed; 225 tons scrap decontaminated and reclaimed off-site; Sludges reclaimed off-site; 850 yd^3 debris disposed of in permitted landfill	38, (1992)
Land treatment plus soil flushing, and bioreactor treatment of water	Land treatment: Capital O&M Soil flushing: Capital O&M Water treatment: Capital O&M Present worth	 $905,598 $126,509/yr. $5,483,950 $58,070/yr. $1,252,725 $744,211/yr. $9,074,062 (1992)	Idaho Pole Company Site, Bozeman, Montana Media: 19,000 yd^3 soil and sediment; 23,000 yd^3 soil in situ; 210 mil. gal. groundwater Contaminants: PCP up to 25 mg/kg; benzo(a)pyrene up to 1.7 mg/kg; dioxins/furans up to 34.2 μg/kg Details: Excavated soil pretreated with oil/H_2O separator; Separated creosote transported off-site; Land treatment unit covers 4 acres with 1 ft. layers; Completed land treatment unit will be closed by capping; Clean fill to replace excavated soil; Inaccessible soils treated by hot water/steam flushing and O_2/nutrient enhanced in situ bioremediation; Groundwater extracted and treated in bioreactor, reinjected to stimulate in situ breakdown	39, (1992)

A. SOIL, SEDIMENT, AND SLUDGE

1.b. BIOLOGICAL TREATMENTS: *EX SITU*

SLURRY-PHASE TREATMENT/BIOREACTORS

Treatment Technology	Cost Elements	Cost	Site Characteristics/Comments	Reference
Slurry-phase treatment	Total treatment cost	$8.6 million	Coleman-Evans Superfund Site, White House, Florida Media: 27,000 yd^3 soil and sediments; groundwater Contaminants: PCP Details: Remediation began Sept. 1992; Treatment train includes soil washing, slurry-phase bioremediation of soil, and solids stabilization; Dioxins have been detected and are being evaluated; Clean-up levels for PCP are 25 ppm in soil and sediments and 1 ppm in groundwater	40, (1991)
Slurry-phase bioreactor	Treatability Design engineering Soil screening and slurry prep Slurry treatment Slurry dewatering Site prep and closure Project admin. Total cost/unit	$200,000 $100,000 $800,000 $700,000 $400,000 $500,000 $200,000 $190 to 200/ton	Southeastern Wood Preserving Superfund Site, Operable Unit 1, Canton, Mississippi Media: 10,500 yd^3 creosote-contaminated waste (14,140 tons) Contaminants: total PAHs from 8000 to 5,000 mg/kg; carcinogenic PAHs from 1000 to 2500 mg/kg Details: Soil excavated and power screened; Prepared slurry transferred to one of four 210,000 gal. reactors (operating vol. 180,000 gal.); Treatment efficiencies were 95% with a treatment criteria of 950 mg/kg total PAHs and 180 mg/kg for benzo(a)pyrene equivalents; Reactors operated in batch mode (8-12 treatment days per batch); Slurry dewatering unit removed excess water for re-use	41, (1994)

A. SOIL, SEDIMENT, AND SLUDGE				
1.b. BIOLOGICAL TREATMENTS: *EX SITU*				
SLURRY-PHASE TREATMENT/BIOREACTORS, continued				
Slurry-phase bioreactor	Total treatment cost (including $12 million for tech. development and pilot-scale demo) Before-treatment costs (mobilization, site prep, testing and analysis) After treatment cost (decommissioning, disposal, site restoration)	$49 million (1993) $16.5 million $5.6 million	French Limited Superfund Site, Crosby, Texas Media: 300,000 tons sludge and soil Contaminants: VOCs up to 400 ppm; PCP up to 750 ppm; SVOCs up to 5000 ppm; metals up to 5000 ppm; PCBs up to 616 ppm Details: 70 mil. gal. petrochemical waste disposed of in unlined lagoon; Large full-scale slurry-phase lagoon bioremediation with Mixflo™ aeration system; Two treatment cells holding 17 mil. gal. each; Tarry sludge dredged, treated separately from lagoon subsoil; Approx. 300,000 tons lagoon sludge/soil treated to <ROD levels	42, (1995)
Slurry-phase bioreactor	Total cost/unit	$65 to $262/$m^3$ ($50 to $200/$yd^3$)	Joliet AAP, Joliet, Illinois Media: soil Contaminants: 1300 mg/kg TNT Details: **Pilot-scale**; Slurry-phase biodegradation of explosives-contaminated soils; Soils excavated and fines treated in bioreactor with indigenous microbes; Attained 10 mg/kg TNT in 15 days	43, (1994)
Slurry-phase bioreactor treatment post soil washing	Total cost/unit (including water treatment, slurry biodegradation, and incineration; cost estimate based on demo)	$168/ton (1989)	Macgillis & Gribbs Industrial Site, New Brighton, Minnesota Media: soils Contaminants: 247 ppm PAHs; 130 ppm PCP, Cu, Cr, As Details: **SITE Program demonstration;** Biotrol, Inc. soil washing process for volume reduction; Fixed-film bioreactor to treat process water; Slurry bioreactor to treat soil washing residuals; Incineration of woody debris; Soil washing removed 87-89% PCP and 83-88% PAHs; Removal of 91-94% PCP in bioreactor	44, (1993)

A. SOIL, SEDIMENT, AND SLUDGE				
1.b. BIOLOGICAL TREATMENTS: *EX SITU*				
SLURRY-PHASE TREATMENT/BIOREACTORS, continued				
Bioreactor treatment of soils plus pump and treat groundwater	Groundwater clean-up Soil clean-up Present worth (includes $32,800 annual O&M for 5-10 yrs., ROD estimate)	$236,000 $365,000 to $448,000 $601,000 to $684,000 (1992)	Jasco Chemical Superfund Site, Mountain View, California Media: groundwater, 1100 yd^3 soil Contaminants: 2.2 ppm 1,1-DCA, 2.6 ppm 1,2-DCA, 170 ppm 1,1-DCE, 142 ppm methylene chloride, 16 ppb vinyl chloride in groundwater; 3400 ppm methylene chloride, 490 ppm trichloroethylene, 170-0 ppm toluene, 270 ppm acetone in soil Details: Groundwater Treatment: On-site construction of liquid-phase carbon adsorption unit; 12 wells from 22 to 35 ft., 3 from 42 to 57.5 ft.; Plume area is 400 ft.; Treated water discharged to municipal sewer system; Continued pump and treat for 10 years; Quarterly monitoring; Soil Treatment: Excavated 1100 yd^3 soil and ex situ treatment in bioreactor with nutrient amendments; Aerobic system with airdraw to pull off VOCs; GAC to treat air stream; Off-site disposal of soils with residual contamination; Costs given as min./max. estimates	45, (1992)
Bioreactor and groundwater treatment	Total operating cost of treating 13,680 gal./day (51,779 L/day) Including O&M costs of utilities maintenance nutritional salts Total capital and R&D costs	$226/day (or $0.0165/gal.) $47.40/day $159.93/day $19.20/day $926,158	Biocraft Laboratories, Walwick, New Jersey Media: groundwater, soil Contaminants: methylene chloride, butanol, dimethyl aniline, acetone; concentrations of 100 to 700 mg/L Details: Physical recovery of soil followed by surface biological treatment in bioreactors with indigenous microbes; Groundwater collection system and biostimulation plant operating at 13,680 gal./day; Treated groundwater reinjected followed by in situ treatment using oxygen enhancement and nutrient amendments; Total operating costs based on treating 13,680 gal./day	46, (1984)

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A. SOIL, SEDIMENT, AND SLUDGE

2. PHYSICAL AND CHEMICAL TREATMENTS

A. SOIL, SEDIMENT, AND SLUDGE

2.a. PHYSICAL/CHEMICAL TREATMENTS: *IN SITU*

SOIL VAPOR EXTRACTION

Treatment Technology	Cost Elements	Cost	Site Characteristics/Comments	Reference
SVE	Source Area D (SVE): Construction O&M Total/lb. removed Source Area G (SVE + GAC): Construction O&M Total/lb. removed Groundwater monitoring Capital Annual operating cost	 $167,000 $67,200 $0.52/lb. $467,000 $76,900 $0.79/lb. $4.3 million $500,000/yr.	Twin Cities Army Ammunition Plant, New Brighton, Minnesota Media: 26,000 ft^2 soil in Source Area D; 68,400 ft^2 soil in Source Area G Contaminants: VOCs in Source Area D; VOCs, especially TCE, in Source Area G Details: SVE treatment included 129 vents from 35 to 55 ft. with one additional deep vent between 125 and 150 ft.; Source Area G had 8000 lbs. GAC to treat off-gas; 226,074 lbs. VOCs removed; Large-scale groundwater monitoring with 300 wells	1, (1992)
SVE	Total capital cost Annual operating cost (estimate)	$5,313,973 $100,000/yr. (1994)	Commencement Bay, South Tacoma Channel Well 12A Superfund Site, Phase 2, Tacoma, Washington Media: 98,203 yd^3 soil Contaminants: 10 to 100 mg/kg VOCs in top 25 ft. of soil; 6200 mg/kg PCA at 30 ft.; 19,000 mg/kg PCA at 40 ft.; 571,000 lbs. VOCs in unsaturated zone Details: SVE with on-site solvent recovery system; 22 vapor extraction wells; GAC to treat off-gas; Estimates from earlier pilot-scale study indicated that 3 to 4 lbs./day/well of VOCs could be removed from upper 30 ft. of soil	2, (1995)

A. SOIL, SEDIMENT, AND SLUDGE				
2.a. PHYSICAL/CHEMICAL TREATMENTS: *IN SITU*				
SOIL VAPOR EXTRACTION, continued				
SVE	Capital cost (installation of wells and vapor extraction system, engineering services) Total O&M for 16 mos. (water quality sampling/ analysis, water level monitoring, engineering services, carbon regeneration, equip. maintenance)	$2.1 million $1.8 million	Fairchild Semiconductor Corporation Superfund Site, San Jose, California Media: 42,000 yd^3 soil Contaminants: TCA, DCE, PCE, xylenes, acetone, Freon-113, isopropyl alcohol; total solvent concentration as high as 4500 ppm; TCA up to 3530 ppm; xylenes up to 941 ppm Details: SVE system with 39 extraction wells, 2 vacuum pumps, vapor treatment system with dehumidification and vapor-phase activated carbon	3, (1995)
SVE	Total treatment cost (project monitoring and control, procurement support, construction, mang., O&M, reporting)	$369,628 (1993) *($2/yd^3)*	Hastings Groundwater Contamination Superfund Site, Well No. 3 Subsite, Hastings, Nebraska Media: 185,000 yd^3 soil Contaminants: CCl_4; soil gas as high as 1234 ppmv at 112 ft. Details: Full-scale system consisted of 10 extraction wells (5 deep, 3 intermediate, 2 shallow); 5 monitoring well probes; Air/H_2O separator, vacuum pump and vapor phase activated carbon to treat off-gas	4, (1995)
SVE	Capital cost (site prep, site work, start-up, engineering, pipes, buildings) Operating cost (lab, labor, utilities, maintenance) Total treatment cost	$297,017 $210,168/yr. (1992) $507,185	North Fire Training Area, Luke Air Force Base, Arizona Media: soil Contaminants: BTEX, TPH Details: SVE included 2 extraction wells at 57 ft.; Thermal oxidation of off-gas; 12,000 lbs. removed in 30 weeks	5, (1995)

A. SOIL, SEDIMENT, AND SLUDGE				
2.a. PHYSICAL/CHEMICAL TREATMENTS: *IN SITU*				
SOIL VAPOR EXTRACTION, continued				
SVE	Field demo budget (site characterization, installation/operation of SVE wells, air/H_2O separators, blowers, lab, engineering support, leased catalytic oxidizer and resin adsorption unit) For 1993 For 1994	 $1.8 million $2.0 million	Site S, Superfund Operable Unit D, McClellan Air Force Base, Sacramento, California Media: soil in waste pit, debris, and vadose zone soils Contaminants: chlorinated and petroleum-based VOCs; PCE, TCE, 1,1-DCE, TCA, 1,2-DCA, Freon-113 Details: 17 vapor extraction wells in 3 contaminant zones; 5 vacuum blowers; 2 vapor/liquid separators; Catalytic oxidation with scrubbers; 113,000 lbs. VOCs extracted in 15 weeks; 150,000 lbs. hexane-equivalent contaminants biodegraded in situ	6, (1995)
SVE	Treatment activities (installation, operation) Before-treatment costs (mobilization, site prep, monitoring, lab) After-treatment costs (including pilot study)	$75,600 (1991) $88,490 $19,560	Rocky Mountain Arsenal Superfund Site, Motor Pool Area Operable Unit 18, Commerce City, Colorado Media: 34,000 yd^3 soil in vadose zone Contaminants: halogenated VOCs, primarily TCE as high as 65 ppm Details: One shallow extraction well at 28 ft.; one deep extraction well at 58 ft.; Liquid/vapor separator tank; GAC for off-gas; 4 clusters of vapor monitoring wells	7, (1995)
SVE	Total treatment cost (mobilization, start-up, operation, sampling and analysis, demob.) Additional costs (attributable to treatment of non-Freon contaminants)	$556,000 (1993) $290,000	Sacramento Army Depot Superfund Site, Tank 2 Operable Unit, Sacramento, California Media: 650 yd^3 soil around UST Contaminants: ethylbenzene, 2-butanone, tetrachloroethylene, xylenes up to 11,000 mg/kg, Freon-113 Details: 8 vacuum extraction wells from 15 to 28 ft.; vapor/liquid separator; Carbon adsorption to treat off-gas	8, (1995)

A. SOIL, SEDIMENT, AND SLUDGE				
2.a. PHYSICAL/CHEMICAL TREATMENTS: *IN SITU*				
SOIL VAPOR EXTRACTION, continued				
SVE with horizontal wells	O&M for one year Total treatment cost	$182,700/yr. (1993) $450,420 *($360/yd^3)*	SMS Instruments Superfund Site, Deer Park, New York Media: 1250 yd^3 soil Contaminants: VOCs 1200 ppm max., SVOCs 1800 ppm max. Details: Soil contaminated in area of leaching pool and UST; SVE system has 2 horizontal extraction wells installed in 15 ft. deep x 2 ft. x 75 ft. long trenches adjacent to contaminated area; Off-gas treated by catalytic incineration with acid gas scrubbing	9, (1995)
SVE	Treatment activities (solids prep/handling, mobilization, start-up and testing, permit, operation, ownership, demobilization) Before-treatment (monitoring, sampling, analysis, demolition and removal of structures)	$1,545,281 (1992) $535,180	Verona Well Field Superfund Site, Thomas Solvent Raymond Road Operable Unit 1, Battle Creek, Michigan Media: 26,700 yd^3 soil Contaminants: PCE and 1,1,1-tetrachloroethane; 1700 lbs. total VOCs in soil Details: 27 contaminated municipal wells; SVE system had 23 extraction wells; Catalytic oxidation and GAC for treatment of off-gas; Total of 45,000 lbs. VOCs removed	10, (1995)
SVE	Present worth (ROD estimate)	$614,414 (1991) *($620/yd^3)*	Tank 2 Operable Unit (OU3), Sacramento Army Depot, Sacramento, California Media: 1000 yd^3 soil Contaminants: MEK max. 15 ppm, ethylbenzene max. 2100 ppm, PCE max. 39 ppm, xylenes max. 11,000 ppm Details: Contamination in 875 ft^2 area down to 31 ft.; SVE is 200 cfm system; Extraction wells from 9 to 18 ft.; Water vapor from air/H_2O separator condensed and treated on-site in already-constructed UV/H_2O_2 system; Off-gas treated in series of 2000 lb. GAC canisters; Cost does not include O&M since remedy will take <1 yr.	11, (1991)

A. SOIL, SEDIMENT, AND SLUDGE				
2.a. PHYSICAL/CHEMICAL TREATMENTS: *IN SITU*				
SVE IN CONJUNCTION WITH OTHER TREATMENT(S)				
Treatment Technology	**Cost Elements**	**Cost**	**Site Characteristics/Comments**	**Reference**
SVE and bioventing	Capital cost (construction, start-up) Operation cost (electricity, fuel, labor, lab, equipment leases for 2 yr. operation) Total treatment cost	$335,000 $132,000/yr. (1990) $599,000 *($120/yd^3)*	JP-4 Fuel Spill Site at Site 914, Hill Air Force Base, Ogden, Utah Media: 5000 yd^3 soil in 13,500 ft^2 area Contaminants: 27,000 gallons JP-4 jet fuel; 20 to 10,000 ppm TPH, avg. 400 ppm Details: Two-phase clean-up: Phase 1 - SVE with 7 vent wells (50 ft.); 31 monitoring wells (between 6 and 55 ft.); 3 neutron access probes to monitor soil moisture; Catalytic incinerator for extracted vapor; Phase 2 - 15 mo. bioventing to reduce soil TPH levels to clean-up goals; 4 vent wells and the monitoring wells from SVE	12, (1995)
Density-driven groundwater sparging with SVE	Capital cost (drill/install wells and sparging system, start-up, project mang.) Operating cost (maintenance, electricity, monitoring)	$156,950 $62,750/yr. (1993)	Amcor Precast, Ogden, Utah Media: groundwater plume area approx. 30,000 ft^2; 7500 yd^3 soil Contaminants: 190 mg/L TPH, 4.7 mg/L benzene, 9.4 mg/L toluene, 8.0 mg/L xylenes, 0.63 mg/L naphthalene max. in groundwater; 1600 ppm TPH, 2.5 ppm toluene, 19 ppm ethylbenzene, 110 ppm xylenes max. in soil Details: Full-scale remediation of groundwater contaminated with diesel and gasoline fuels; 12 groundwater sparging wells at 18 ft.; 3 down-gradient extraction wells at 20 ft.; 3 vertical extraction wells; In situ density-driven groundwater sparging, groundwater recirculation, and SVE	13, (1995)

A. SOIL, SEDIMENT, AND SLUDGE				
2.a. PHYSICAL/CHEMICAL TREATMENTS: *IN SITU*				
SVE IN CONJUNCTION WITH OTHER TREATMENT(S), continued				
Air sparging and SVE	Initial pilot study Treatment system O&M $1500/mo. for 6 mos. Electricity $600/mo. for 6 mos. Total treatment cost	$90,000 $165,000 $9000 $3600 $267,000 (1995)	UST Site, Big Rapids, Michigan Media: 43,200 ft^2 soil; free product floating on surface water and in groundwater Contaminants: 12% VOCs by volume; gasoline Details: Site contained 5 leaking USTs and gasoline lines; Air sparging provided in situ removal of dissolved VOCs from groundwater; Vacuum extraction used during air sparging to control and capture the stripped contaminants in the sparge area; Automated Soil Vent Trailer (ASVT) with Shallow Tray® H_2O treatment system; 7 vapor extraction wells and 15 air sparging wells, plus 640 feet of trenching to connect VE and SP wells; GAC to treat off-gas	14, (1995)
SVE plus ex situ bioremediation and pump and treat	Total treatment cost	$12,636,000 (US, 1995)	Abandoned Coal Processing Plant and Coke Works, Derwenthaugh, United Kingdom Media: 12,000 m^3 water; 94,000 m^3 soil Contaminants: benzene, phenols, PAHs Details: Installed a cut-off wall through shallow aquifer to prevent river water from entering zone of depression; Free phase and vapor recovery through liquid/gas separator and GAC; 43 wells at 5 m depths with dual vacuum extraction; Groundwater pumped at 100 m^3/day; Precipitated metals and chemically oxidized cyanide and sulfides; Water filtered and discharged to river; 3000 kg oil recovered; 28,000 m^3 landfarmed with inorganic amendments; Clean soil encapsulated and stored on-site	15, (1995)

A. SOIL, SEDIMENT, AND SLUDGE				
2.a. PHYSICAL/CHEMICAL TREATMENTS: *IN SITU*				
SVE IN CONJUNCTION WITH OTHER TREATMENT(S), continued				
SVE plus pump and treat with GAC	Capital cost O&M Present worth (ROD estimate)	$1,951,500 $249,000/yr. $5,451,000 (1991)	Garden State Cleaners, Buena Borough, New Jersey Media: approx. 1600 yd^3 soil; 1.6 bil. gal. groundwater Contaminants: 6.1 ppm TCE, 1300 ppm PCE, 8.1 ppm acetone, 0.5 ppm methylene chloride max. in soil; 13 ppm TCE and 1.9 ppm PCE max. in groundwater Details: SVE system operating 6 to 9 mos.; Contaminated air/water flows to air/H_2O separator, contaminated water pumped into treatment system and air stream treated with GAC; Estimated 70 yrs. to treat entire plume; 13 deep and 7 medium extraction wells operating at 1000 gpm; 10 injection wells for treated water	16, (1991)

A. SOIL, SEDIMENT, AND SLUDGE

2.a. PHYSICAL/CHEMICAL TREATMENTS: *IN SITU*

SOLIDIFICATION/STABILIZATION

Treatment Technology	Cost Elements	Cost	Site Characteristics/Comments	Reference
In situ solidification/ stabilization	Total cost/unit	$111 to $194/ton	Hialeah, Florida Media: soil Contaminants: inorganics Details: Drive auger used deep in contaminated zone; Additive slurry and water stabilized soil in situ	17, (1994)

A. SOIL, SEDIMENT, AND SLUDGE

2.b. PHYSICAL/CHEMICAL TREATMENTS: *EX SITU*

SOIL WASHING

Treatment Technology	Cost Elements	Cost	Site Characteristics/Comments	Reference
Soil washing	Total cost/unit	$300/hr.	Montclair Superfund Site, Montclair, New Jersey Media: soils Contaminants: low-level radioactive waste (LLRW) Details: Remediation level attained was 11 pCi/g; Use of attrition mill, classifiers, and filter press to reduce amount of LLRW for disposal; 55% volume reduction	18, (1994)
Soil washing	Treatment cost of first 11,000 kgs (25,000 lbs.) Cr(VI)	$88/kg ($40/lb.)	United Chrome Product, Corvallis, Oregon Media: 8 acre shallow aquifer plume; soil Contaminants: max. upper aquifer contamination of 19,000 mg/L Cr(VI), avg. 1923 mg/L Details: 100,000 gal. extraction system with 2 infiltration basins and 1 infiltration trench; 23 shallow extraction wells; Ran for 3 years and treated 9.7 MM gal. H_2O with 26,732 lbs. Cr(VI) removed; Treatment costs expected to double as concentration of Cr(VI) drops in order to reach 10 mg/L level	19, (1993)
Soil washing	Total cost/unit (projected from pilot scale)	$151/metric ton ($137/ton)	Escambia Wood Treating Company Superfund Site, Pensacola, Florida Media: soils Contaminants: 550 to 1700 ppm PAH; 48 to 210 ppm PCP Details: **Pilot scale**; Used particle size classification and surfactant addition; Remaining soil volume contained 45 ppm PAHs and 3 ppm PCPs	20, (1994)

A. SOIL, SEDIMENT, AND SLUDGE				
2.b. PHYSICAL/CHEMICAL TREATMENTS: *EX SITU*				
SOIL WASHING, continued				
Soil washing	Total cost (including off-site disposal of sludge cake)	$7.7 million (1993) *($400/yd^3)*	King of Prussia Technical Corporation Superfund Site, Winslow Township, New Jersey Media: 19,200 tons soil and sludge Contaminants: metals including Cr, Cu, Ni, Hg, Pb, As, Be, Cd, Se, Ag, and Zn; highest concentrations found in sediments were 8010 mg/kg Cr, 9070 mg/kg Cu, and 100 mg/kg Hg; highest concentrations in sludges were 11,300 mg/kg Cr, 16,300 mg/kg Cu, 389 mg/kg Pb, and 11,100 mg/kg Ni Details: Demonstration ran Jan. to Oct. 1992 with soil washing feasibility study; Full-scale demo at Heidamij plant, the Netherlands, on 1000 tons soil; Full-scale on-site soil washing system with selective excavation using XRF (which reduced soil volume by a factor of 2), screening, soil separation using hydrocyclones, froth flotation, and sludge management; Water reused for wet screening; Treated soil used as backfill at site	21, (1995)
Soil washing	Capital costs: Construction Site development Utilities Transportation/set-up Total Capital Operating costs: Direct Indirect Overhead Total Operating Total treatment cost	 $950,000 $50,000 $30,000 $40,000 $1,070,000 $98,980/mo. $23,000 $16,000 $129,980/mo. $3,173,540 or $21/yd^3	Montclair/West Orange Radium Superfund Site, New Jersey Media: 323,000 yd^3 soil Contaminants: 40 pCi/g Ra-226 primarily from radium ore processing; also U-235, U-238, and Th-230 Details: **Pilot plant demonstration**; Soil washing plant used attrition, screening, and wet classification; VORCE (volume reduction/chemical extraction) recovered 54% of material; 46% needed disposal; Capital costs relatively fixed; Treating 20 tons/hr.; Soils at surface reduced to 5 pCi/g and soils distant from dwellings reduced to 15 pCi/g; Remediation took 23 mos.	22, (1993)

A. SOIL, SEDIMENT, AND SLUDGE				
2.b. PHYSICAL/CHEMICAL TREATMENTS: *EX SITU*				
SOIL WASHING, continued				
Soil washing	Treatment cost/unit	$100/tonne (Canadian)	Ataratiri Site, Toronto, Ontario, Canada Media: 500,000 tons soil Contaminants: heavy metals, PAHs Details: 32 hectacre site with full-scale treatment; Integrated treatment process of soil washing and metal recovery (leaching and chelation absorption of leached metals); 84% to 86% contaminated soil was recovered for re-use; 75% recovery of oil/grease and 95% recovery of PAHs for secondary treatment	23, (1995)
Sediment washing	Total treatment cost for 10,000 yd^3 Total treatment cost for 100,000 yd^3	$54/$yd^3$ $24/$yd^3$	US Army Corps of Engineers Saginaw Bay Confined Disposal Facility, Saginaw Bay, Michigan Media: river sediment Contaminants: PCBs, avg. concentration 1.2 mg/kg in feed sediments (range = 0.74 to 3.2 mg/kg) Details: **Pilot scale**; Bergman USA's sediment washing process using hydrocyclones to separate slurries; Treated volume reduced to 20 to 30% of original sediment; 0.21 mg/kg PCBs in washed sand fraction with 83% reduction	24, (1995)
Soil washing and incineration	Total treatment cost (ROD estimate)	$10.3 million	Arkwood Inc. Superfund Site, Omaha, Arkansas Media: 21,000 yd^3 soil and sludge; 7000 yd^3 debris for incineration Contaminants: PCP and creosote contamination in surface water, soil, and debris; PAHs, dioxins Details: 15 acre site; Excavated 21,000 yd^3 soil/sludge for soil washing; On-site incineration of soil washing residuals; Incineration of free creosote; Backfilled with decontaminated material; Capping and revegetation of site; Long-term groundwater monitoring	25, (1995)

A. SOIL, SEDIMENT, AND SLUDGE				
2.b. PHYSICAL/CHEMICAL TREATMENTS: *EX SITU*				
SOIL WASHING, continued				
Soil washing with bioreactor and incineration	Treatment cost/unit (including water treatment, slurry biodegradation, and incineration)	$168/ton (1989)	Macgillis & Gribbs Site, New Brighton, Minnesota Media: soils Contaminants: 247 ppm PAHs; 130 ppm PCP, Cu, Cr, As Details: **SITE Program demonstration;** Biotrol, Inc. soil washing process for volume reduction; Fixed-film bioreactor to treat process water; Slurry bioreactor to treat soil washing residuals; Incineration of woody debris; 87-89% removal of PCP from soil washing and 91-94% in bioreactor; 83-88% removal of PAHs from soil washing	26, (1993)
Soil washing with ex situ bioremediation	Demonstration project cost	$8,000,000 (Canadian dollars, 1992) *($1900/yd^3, Canadian)*	Toronto Harbour Commission's (THC) Soil Recycling Demonstration Project, Toronto, Ontario, Canada Media: 4400 tons soil Contaminants: Cd, As, Cu, Pb, Hg, Zn, Ni, PAHs Details: **Full-scale demonstration project**; Integrated soil washing with metal extraction by chelation; Bergman USA's chemical attrition scrubbing system treated up to 10 ton/hr. on-site; BSN's high pressure wash system operated at 50 ton/hr. off-site; Ex situ aerobic bioremediation in upflow air reactors reduced organics	27, (1993)
Soil washing with in situ aquifer biodegradation	Total treatment cost (including capital and O&M; 5 yr. duration)	$1,191,000	Union Pacific Railroad, Pocatello, Idaho Media: soil; upper level aquifer (580 mil. gal. H_2O) Contaminants: NAPLs Details: Two soil washing processes: Bergman USA's on-site chemical attrition scrubbing system (5-10 ton/hr.) plus BSN's off-site high-pressure wash system (50 ton/hr.); 11 extraction wells operating at 20 gpm each; Installed recovery wells, treatment system, and infiltration galleries; Treated water enhanced with O_2/nutrients to stimulate in situ biodegradation during soil flushing	28, (1993)

A. SOIL, SEDIMENT, AND SLUDGE

2.b. PHYSICAL/CHEMICAL TREATMENTS: *EX SITU*

SOLIDIFICATION/STABILIZATION

Treatment Technology	Cost Elements	Cost	Site Characteristics/Comments	Reference
Ex situ solidification/ stabilization	Total cost/unit	$80/metric ton ($73/ton)	Portable Equipment Salvage, Clackamas, Oklahoma Media: soils Contaminants: Cu, Pb, Zn Details: Dry alumina, calcium, and silica blended in reaction vessel to solidify soils ex situ; 93.2 to 99.9% reduction in heavy metal TCLP levels	29, (1994)
Ex situ solidification/ stabilization	Total cost/unit	$94/metric ton ($85/ton)	Naval Construction Battalion Center, Port Hueneme, California Media: soils Contaminants: heavy metals, spent blasting abrasives Details: Spent blasting abrasives screened and mixed with portland cement and soluble silicates; Level reduced to <5 ppm TCLP	30, (1994)

A. SOIL, SEDIMENT, AND SLUDGE

2.b. PHYSICAL/CHEMICAL TREATMENTS: *EX SITU*

VACUUM EXTRACTION

Treatment Technology	Cost Elements	Cost	Site Characteristics/Comments	Reference
Ex situ vacuum extraction with horizontal wells	Total cost	$2 million (1993) *($1000/yd^3)*	EPA Removal Action, Basket Creek Surface Impoundment, Georgia Media: 2000 yd^3 soil Contaminants: TCE, PCE, MEK, BTEX Details: Ex situ vacuum extraction done on soil pile with horizontal wells; Enclosure built over site; Residual soils disposed of in non-hazardous landfill; VOCs captured and destroyed with incineration (70,000 lbs. VOCs total); Surface impoundment built for disposal of waste solvents	31, (1994)

A. SOIL, SEDIMENT, AND SLUDGE

2.b. PHYSICAL/CHEMICAL TREATMENTS: *EX SITU*

PHYSICAL SEPARATION/CHEMICAL EXTRACTION

Treatment Technology	Cost Elements	Cost	Site Characteristics/Comments	Reference
Physical separation/ chemical extraction	Total cost/unit	$1000/yd^3 (1992)	DOE Demonstration, Idaho National Engineering Laboratory, Idaho Media: sediments Contaminants: radionuclides (Cs-137) and metals Details: Remediation involved removing contaminants from leachate by ion exchange, reverse osmosis, precipitation, and evaporation; Materials were screened, segregated, and leached with hot nitric acid; Residuals were solidified and leachate was calcined	32, (1994)
Solvent extraction	Total treatment cost for 25,000 yd^3 sediment 100,000 yd^3 sediment	 $174/yd^3 $139/yd^3	US Steel, Gary Works, Grand Calumet River, Indiana Media: river sediment Contaminants: 12.1 mg/kg PCBs, avg.; 548 mg/kg PAHs, avg. in sediment feed Details: **Pilot scale**; Resources Conservation Co.'s Basic Extractive Sludge (BEST) extraction using triethylamine as solvent to separate PAHs and PCBs from sediments; Concentrated them into oily residue; Residual contained avg. 0.04 mg/kg PCBs (99.7% reduction) and 22 mg/kg PAHs (96.0% reduction)	33, (1995)
Critical fluid extraction	Total treatment cost (ROD/contractor estimate)	$34 million *($361.70/yd^3)*	United Creosoting Superfund Site, Conroe, Texas Media: 94,000 yd^3 soil, 100 acre site Contaminants: PAHs, PCPs, dioxins Details: Excavation, on-site treatment of soil with critical fluid extraction; Liquid propane solvent; Off-site incineration of concentrated residues; Waste water recycled, discharged; Backfilled site with treated soil	34, (1995)

A. SOIL, SEDIMENT, AND SLUDGE

2.b. PHYSICAL/CHEMICAL TREATMENTS: *EX SITU*

OXIDATION/REDUCTION

Treatment Technology	Cost Elements	Cost	Site Characteristics/Comments	Reference
Oxidation/reduction	Total cost	$230,000	Cement Products Manufacturing Site, Salt Lake City, Utah Media: groundwater; 6400 to 14,000 yd^3 soil and sediment Contaminants: predominantly BTEX and TPH; groundwater concentrations: benzene from 5 to 4600 µg/L; toluene from 4 to 1800 µg/L; ethylbenzene from 3 to 600 µg/L; xylene from 10 to 7000 µg/L; TPH from 700 to 66,000 µg/L Details: 25,000 ft^2 area under remediation; Soil contaminated to depths between 7 and 15 ft. across site; Per unit costs depend on how much contaminated media total needs treatment; Terra Vac, Inc. technology	35, (1996)
Oxidation/reduction	Total cost	$10,000	Gasoline Service Station, Berkeley, California Media: groundwater; 1100 yd^3 soil and sediment Contaminants: groundwater avg. conc.: 600 µg/L benzene; 11,000 µg/L TPH Details: Area is 5000 ft^2 to a depth of 6 ft.; Terra Vac, Inc. technology	36, (1996)

2.c. PHYSICAL/CHEMICAL SOIL TREATMENT REFERENCES

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A. SOIL, SEDIMENT, AND SLUDGE

3. THERMAL TREATMENTS

A. SOIL, SEDIMENT, AND SLUDGE

3.a. THERMAL TREATMENTS: *IN SITU*

IN SITU VITRIFICATION

Treatment Technology	Cost Elements	Cost	Site Characteristics/Comments	Reference
In situ vitrification	Vitrification activities Before-treatment (mobilization, site admin., site prep, sampling/analysis) After-treatment (backfill and restoration, drainage structure, demobilization)	$800,000 (1994) $800,000 $90,000	Parsons Chemical/ETM Enterprises Superfund Site, Grand Ledge, Michigan Media: 3000 yd^3 soil and sediment Contaminants: pesticides, heavy metals, dioxins, phthalates, PAHs; dioxin at 1.13 µg/kg; range of other contaminants was 0.99 mg/kg to 430 mg/kg Details: ISV system consisted of 9 melt cells (26 ft^2 in 16 ft. deep trench); Contaminated soil excavated and staged at site; 8 melts, each 10-20 days using 559,000-1,100,000 kWhr; Air emissions control system with off-gas collection hood, water scrubber, and thermal oxidizer	1, (1995)
In situ vitrification	Total cost/unit	$300 to $400/ton (1993)	DOE Demonstration, Hanford Reservation, Washington Media: soil Contaminants: organics, inorganics, radionuclides Details: **Field demonstration**; Joule heating of soil through the application of electrodes; Organics were destroyed, inorganics were vitrified	2, (1994)

A. SOIL, SEDIMENT, AND SLUDGE

3.a. THERMAL TREATMENTS: *IN SITU*

THERMALLY-ENHANCED SVE

Treatment Technology	Cost Elements	Cost	Site Characteristics/Comments	Reference
Thermally-enhanced SVE	Total cost/unit	$330 to $415/$m^3$ ($252 to $317/$yd^3$)	Annex Terminal, San Pedro, California Media: soil Contaminants: VOCs, SVOCs Details: In situ steam and air stripping of soil via hollowstem, rotating blade drills; Removal of 85% VOCs and 55% SVOCs	3, (1994)
Thermally-enhanced SVE	Capital O&M costs for a 1000 gpm system	$4.3 million $630,000/yr	Lockheed Aeronautical Systems, Burbank, California Media: groundwater, soil Contaminants: 2.2 ppm TCE and 11 ppm PCE in groundwater; 6000 ppm VOCs in soil (soil gas) Details: Integrated groundwater stripping and soil system; Running at 1000 gpm; Removal of >98% VOCs	4, (1994)
Thermally-enhanced SVE	Total cost/unit	$16 to $33/metric ton ($15 to $30/ton)	Sandia National Laboratory, Albuquerque, New Mexico Media: landfill Contaminants: organics, firetraining and chemical production wastes Details: Thermal enhancement by integrated resistive (powerline) and radio frequency (microwave) heating; Costs dependent on soil moisture	5, (1994)

A. SOIL, SEDIMENT, AND SLUDGE				
3.a. THERMAL TREATMENTS: *IN SITU*				
THERMALLY-ENHANCED SVE, continued				
Thermally-enhanced SVE	Total cost/unit	$45/ton	Volkfield, Wisconsin Media: sand Contaminants: VOCs, SVOCs Details: In situ IITRI design; System run in shallow sand; Removal of 99% VOCs and 83-99% SVOCs	6, (1994)
Thermally-enhanced SVE	Total treatment cost/unit Treatment cost/lb. VOC removed Total treatment price	$63/$yd^3$ soil $11/lb. VOC $1.95 million	Sand Creek Superfund Site, Operable Unit 1, Commerce City, Colorado Media: 31,000 yd^3 soil Contaminants: 177,000 lbs. VOCs including PCE, TCE, chloroform, methylene chloride Details: Thermally-enhanced SVE with vertical and horizontal wells interchanged with dual vacuum extraction, heated vapor reinjection, and air sparging; Upward diffusion of volatile compounds to unsaturated vadose zone; GAC to treat vapor with two 8000 lb. carbon vessels; 3 well fields with 31 vertical wells, 1 horizontal well; Peripheral wells operated in vacuum service; Conformation borings at 32 locations with on-site soil analysis; Removed 3300 lbs. VOCs	7, (1995)
Thermally-enhanced SVE	Total cost/unit	$15 to $20/ton (1993)	DOE Demonstration, Sandia National Laboratory, Albuquerque, New Mexico Media: soil Contaminants: VOCs Details: **Field demonstration** run at 200-1600V and 100°C; Used resistive heating and radiofrequency heating; Costs highly dependent on soil moisture content and treatment temperature; Demo did not include treatment of off-gas	8, (1994)

A. SOIL, SEDIMENT, AND SLUDGE

3.b. THERMAL TREATMENTS: *EX SITU*

THERMAL DESORPTION

Treatment Technology	Cost Elements	Cost	Site Characteristics/Comments	Reference
Thermal desorption	Total treatment cost (contractor estimate; salaries, wages, leases, supplies, subcontracts, fuel; 80% of cost associated with actual treatment)	$2.9 million (1987) *($250/yd^3)*	McKin Company Superfund Site, Gray, Maine Media: 11,500 yd^3 soil Contaminants: halogenated VOCs, PAHs; TCE as high as 1500 mg/kg; methylene chloride as high as 49 mg/kg; xylenes as high as 21 mg/kg Details: On-site treatment included ambient air monitoring; Thermal desorption system included rotary kiln desorber with off-gas filtration, baghouse, scrubber, and carbon adsorption	9, (1995)
Thermal desorption	Total treatment cost (solids prep/handling, mobilization, start-up, system operation, demobilization - estimate) Before-treatment (mobilization, prep work, monitoring, sample testing, treatability study)	$849,996 (1993) $252,582	TH Agriculture and Nutrition Company Superfund Site, Albany, Georgia Media: 4300 tons soil Contaminants: organochlorine (OCL) pesticides at >1000 mg/kg Details: Thermal desorption used to treat 4300 tons stockpiled soil with rotary kiln thermal desorber at 833 to 1080°F and 15 min. resident time; Off-gases routed through baghouse, a water-quenching unit, a reheater, and a vapor-phase carbon adsorption bed	10, (1995)

A. SOIL, SEDIMENT, AND SLUDGE				
3.b. THERMAL TREATMENTS: *EX SITU*				
THERMAL DESORPTION, continued				
Thermal desorption	Total treatment cost (solids prep/handling, start-up, testing, permits, capital equipment, demobilization) Before-treatment (mobilization, site prep, monitoring, sampling, testing and analysis)	$2,474,000 (1992) $900,000	Outboard Marine Corporation Superfund Site, Waukegan, Illinois Media: 12,755 tons soil and sediment Contaminants: 2400 to 23,000 mg/kg PCBs Details: SoilTech's Anaerobic Thermal Processor (ATP) used on-site; Rotary kiln desorber; Air emissions controlled using cyclones, baghouse, scrubbers, fractionator, condenser, gas/oil/H_2O separator, and carbon adsorption; Water treated on-site with sand filtration, Klensorb® filtration, UV oxidation, cartridge filtration, and carbon adsorption	11, (1995)
Thermal desorption	Total treatment costs for 10,000 yd^3 Total treatment costs for 100,000 yd^3	$535/$yd^3$ $352/$yd^3$	US Army Corps of Engineers Dike No. 4, Confined Disposal Facility, Buffalo River, New York Media: river sediment Contaminants: PAHs, avg. 7.9 mg/kg in feed sediments Details: **Pilot scale**; Thermal desorption with Remediation Technologies, Inc. system; Two hollow augers using molten eutectic material to heat sediments between 150 and 260°C; Volatilizing H_2O and organics, condensing volume of PAHs to oily residue; Reduced PAHs by 78%; Costs do not include dredging and disposal of treated solids/residues	12, (1995)
Low temperature thermal desorption	Total cost/unit	$410 to $798/metric ton ($373 to $725/ton)	Tinker Air Force Base, Oklahoma City, Oklahoma Media: 3000 yd^3 soil Contaminants: VOCs, SVOCs, BTEX Details: Low temperature thermal treatment (LT^3); 99.9% BTEX removed; Costs dependent on soil moisture	13, (1994)

A. SOIL, SEDIMENT, AND SLUDGE				
3.b. THERMAL TREATMENTS: *EX SITU*				
THERMAL DESORPTION, continued				
Thermal desorption and dehalogenation	Total treatment cost (solids prep, startup, equipment, operation) Before-treatment (mobilization, prep work, monitoring) After-treatment	$11.6 million (1991) $908,000 $3.4 million	Wide Beach Development Superfund Site, Brant, New York Media: 42,000 tons stockpiled soil Contaminants: 10 to 5000 mg/kg PCBs from waste oil Details: SoilTech's mobile Anaerobic Thermal Processor (ATP) system used in conjunction with alkaline polyethylene glycol (APEG) dechlorination; Retort zone temp. 1160°F with 30 to 40 min. residence time; Air emissions control with cyclones, baghouse, scrubber, fractionator, condenser, gas/oil/H_2O separator, and carbon adsorption; Water treated on-site	14, (1995)
Low temperature thermal desorption	Total cost	$250,000 (1992) *($80/yd^3)*	EPA Removal Action, Drexler-RAMCOR, Washington Media: 3000 yd^3 soil Contaminants: petroleum hydrocarbons, polynuclear aromatics, BTEX; max. TPH 70,000 ppm; avg. TPH 15,000 to 20,000 ppm Details: Soil initially excavated and screened; Rock washing and steam cleaning decontaminated larger soil matrix; Used for backfill on-site; Low temp. thermal desorption used to treat 3000 residual tons; Operated 16 hrs./day, 12 to 15 tons/hr. at 700°F; Wastewater treated on-site with carbon filtration	15, (1994)
Low temperature thermal desorption	Total cost/unit Cost for treatment of off-gases	$81 to $176/metric ton ($74 to $160/ton) $410 to $798/metric ton ($87 to $184/ton)	Letterkenny Army Depot, Chambersburg, Pennsylvania Media: soil Contaminants: up to 20,000 ppm VOCs Details: USACE's Holo-Flite Screw Thermal Processor; Removal of 99.95% VOCs;	16, (1994)

A. SOIL, SEDIMENT, AND SLUDGE				
3.b. THERMAL TREATMENTS: *EX SITU*				
THERMAL DESORPTION, continued				
Low temperature thermal desorption	Total cost/unit	$410 to $798/metric ton ($373 to $725/ton)	Letterkenny Army Depot, Chambersburg, Pennsylvania Media: soil Contaminants: TCE, PCE, DCE, xylene; concentrations up to 27,000 ppm Details: Low Temperature Thermal Treatment (LT^3); ≤ 1.8 ppm attained; Costs dependent on soil moisture content	17, (1994)
High temperature thermal desorption	Total cost/unit	$182/metric ton ($165/ton)	Alaskan Battery Enterprises Superfund Site, Fairbanks, Alaska Media: soils Contaminants: 2280 to 10,374 ppm Pb Details: **Pilot scale**; System used gravity separation and particle size classification; Pb levels reduced to >2541 ppm	18, (1994)
High temperature thermal desorption	Total cost/unit	$151/metric ton ($137/ton)	Escambia Wood Treating Company Superfund Site, Pensacola, Florida Media: soils Contaminants: 550 to 1700 ppm PAHs, 48 to 210 ppm PCPs Details: **Pilot scale**; System used particle size classification and surfactant addition; Reduced to 45 ppm PAHs and 3 ppm PCPs; Costs projected from pilot scale results	19, (1994)

A. SOIL, SEDIMENT, AND SLUDGE

3.b. THERMAL TREATMENTS: *EX SITU*

INCINERATION

Treatment Technology	Cost Elements	Cost	Site Characteristics/Comments	Reference
Incineration	Total cost/unit	$180 to $800/metric ton ($164 to $730/ton)	Peak Oil Site, Tampa, Florida Media: soil Contaminants: oil sludge (PCBs, lead) Details: Electric infrared mobile incineration unit	20, (1994)
Incineration	Total cost/unit	$180/metric ton ($173/ton)	Savanna Army Depot, Savanna, Illinois Media: 75,000 tons soil Contaminants: 1000 ppm TNT Details: Full-scale transportable incineration system; Treated 75,900 tons soil; <1 ppm TNT in ash residue	21, (1994)
Incineration	Total cost/unit	$200/metric ton ($180/ton)	Lauder Salvage Yard, Beardstown, Illinois Media: soil Contaminants: 12,000 ppm PCBs Details: Full-scale transportable incineration system; Disposed ash contained <1 ppm PCBs	22, (1994)
Fluidized bed incineration	For 20,000 - 50,000 tons For 10,000 - 15,000 tons (Costs for incineration only, not including excavation)	$150 to $300/ton $350 to $400/ton	Formerly Operating Oil Field, Kenai Peninsula, Alaska Media: 80,000 tons soil Contaminants: PCBs Details: Clean-up level of 12 ppm (24 ppm for areas with difficult access and low risk); Excavation of soils from around still-functioning natural gas pipelines and structures; Site includes on-site lab, health and safety office, feed prep building, and power generation	23, (1991)

A. SOIL, SEDIMENT, AND SLUDGE				
3.b. THERMAL TREATMENTS: *EX SITU*				
INCINERATION, continued				
Incineration and off-site reclamation	Site prep Sludge liquidation Transportation Reclamation Total	$300,000 $1 million $550,000 $1.0 million $3.1 million *($1000/yd^3)*	Broderick Wood Products Superfund Site, Denver, Colorado Media: >3200 yd^3 sludge Contaminants: creosote; sludge also contained PCP, PAHs, VOCs, chlorinated dioxins, furans Details: Water biologically treated and discharged as production wastewater; Recovered coal tar oil was used as normal feedstock; Residual solids were managed as K001 waste	24, (1994)
Incineration and soil washing	Total treatment cost (ROD estimate)	$10.3 million	Arkwood Inc. Superfund Site, Omaha, Arkansas Media: 21,000 yd^3 soil and sludge; 7000 yd^3 debris for incineration Contaminants: PCP and creosote contamination in surface water, soil, and debris; PAHs, dioxins Details: 15 acre site with contaminated wood-treatment facility, sink-holes, ditches, and wood storage; On-site incineration of soil washing residuals and debris; Incineration of free creosote; Decontaminated materials used as backfill; Capping and revegetation of site with long-term groundwater monitoring	25, (1995)
Infrared thermal destruction	Total for thermal treatment of soils	$1.4 million *($1000/yd^3)*	Twin Cities Army Ammunition Plant, New Brighton, Minnesota Media: 1400 yd^3 excavated soil in Source Area D Contaminants: PCBs at maximum of 210 ppm Details: Thermal treatment included excavating 1400 yd^3 soil, temporary securement, full-scale mobile incinerator; Organic vapor analyzer used during incineration for monitoring	26, (1992)

A. SOIL, SEDIMENT, AND SLUDGE				
3.b. THERMAL TREATMENTS: *EX SITU*				
INCINERATION, continued				
Thermal destruction	Total treatment cost	$2.4 million	Former Explosives Manufacturing Facility, New Jersey Media: soil Contaminants: nitrocellulose totaling 55,000 lbs. mixed with DNB, DNT, TNT Details: Open burning of nitrocellulose in burn unit; 2 m layer of excavated nitrocellulose spread in burn unit, mixed with kerosene and 1 lb. powder ignition charge for detonation; Residual ash removed and disposed of at off-site landfill; Residual contained <6260 mg/kg nitrocellulose	27, (1994)
Incineration and pump and treat	Total treatment cost (ROD estimate)	$47.5 million	Texarkana Wood Preserving Company Superfund Site, Texas Media: 77,000 yd^3 soil, affected sediments, and sludges; 16 million gal. groundwater Contaminants: creosote, dioxin, PAHs, pesticides, phenols including PCP Details: 25 acre site; Excavation and incineration of soils, sediment, and sludges near processing ponds; On-site backfilling of ash with capping and revegetation; Pump and treat shallow groundwater with GAC; Reinjection of treated water on-site; Clean-up levels were 3 ppm carcinogenic PAHs, 2350 ppm total PAHs, 150 ppm PCP, and 20 ppb combined dioxins and furans	28, (1995)

A. SOIL, SEDIMENT, AND SLUDGE				
3.b. THERMAL TREATMENTS: *EX SITU*				
INCINERATION, continued				
Incineration, in situ bioremediation, and pump and treat	Bioremediation, excavation, and incineration: Capital costs O&M Present worth Pump and treat: Capital costs O&M Present worth	 $29 million $500,000/yr. $40 million (1993) $2 million $250,000/yr. $6 million (1993)	American Creosote Works Inc. Superfund Site, Winnfield, Louisiana Media: 25,000 yd^3 sludge and 250,000 yd^3 soil; shallow groundwater Contaminants: PAHs, PCP Details: Excavation and incineration of 25,000 yd^3 highly contaminated sludge and tars; Decontaminated ash used on-site as fill; Pump and separate NAPLs from sub-surface zones of pooled product to promote biodegradation of PCP and PAHs; Incineration of NAPLs; Reinjection of water to promote flushing of contaminants into 250,000 yd^3 in situ biotreatment zone; O_2 and nutrients added; 30 yr. remediation	29, (1993)
Rotary kiln incineration plus pump and treat groundwater	Thermal destruction: Capital costs O&M Present worth Pump and treat: Capital costs O&M Present worth	 $42 million $60,000/yr. $43.1 million (1990) $3.4 million $1.0 million/yr. $4.4 million (1990)	Operable Unit 1, Texarkana Wood Preserving Company Site, Texarkana, Texas Media: 77,000 yd^3 soil, sludge, and sediments; 16 mil. gal. shallow groundwater Contaminants: PCP max. conc.: 1400 ppm in soil, 4.1 ppm in groundwater, 5100 ppm in sludge; benzo(a)pyrene max. conc.: 1396 ppm in soil, 0.137 ppm in groundwater, 3918 ppm in sludge; dioxin max. conc.: 76 ppm in ppb in soil, 10.6 ppb in groundwater, 302 ppb in sludge Details: Soil treatment includes two rotary kiln incinerators operating 24 hrs./day at 4 yd^3/hr.; DRE of 99.99%; Soils excavated and stored on-site prior to incineration; Ash used as backfill with topsoil and revegetation cover; Pump and treat of shallow groundwater; GAC to treat off-gas; Water reinjected to aquifer; Estimated 10 yr. groundwater treatment	30, (1990)

A. SOIL, SEDIMENT, AND SLUDGE

3.b. THERMAL TREATMENTS: *EX SITU*

VITRIFICATION

Treatment Technology	Cost Elements	Cost	Site Characteristics/Comments	Reference
Ex situ vitrification	Total cost/unit	$2000/metric ton ($1816/ton)	DOE Site, Butte, Montana Media: soils Contaminants: 28,000 ppm zinc oxide; 1000 ppm hexachlorobenzene Details: Plasma arc centrifugal treatment unit; Remediated to TCLP levels for each contaminant	31, (1994)
Ex situ vitrification	Total cost/unit	$495 to $605/metric ton ($450 to $550/ton)	Babcock & Wilcox, Alliance Research Center, Alliance, Ohio Media: soils Contaminants: 49.9 ppm Cd, 2.67 ppm Cr, 97.1 ppm Pb, anthracene, dimethylphthalate Details: **Pilot scale**; Mixed heavy metal and organic waste fed into cyclone furnace; Contaminant levels reduced to TCLP of <0.12 ppm Cd, 0.22 ppm Cr, and <0.31 ppm Pb; >99.99% DRE for anthracene and dimethylphthalate	32, (1994)
Ex situ vitrification	Total cost/unit	$220 to $1020/metric ton ($200 to $930/ton)	HRD Facility, Monaca, Pennsylvania Media: soils Contaminants: 54,000 ppm Pb, 410 ppm Cd, 5200 ppm As, 860 ppm Ba, 88 ppm Cr Details: Mixed heavy metal and organic waste fed into hot reducing atmosphere; Residue contained 0.474 ppm As, 0.175 ppm Ba, <0.05 ppm Cd, <0.06 ppm Cr, and <0.33 ppm Pb	33, (1994)

A. SOIL, SEDIMENT, AND SLUDGE				
3.b. THERMAL TREATMENTS: *EX SITU*				
VITRIFICATION, continued				
Plasma ARC vitrification	Total cost/unit	$750 to $1900/ton (1991)	EPA and DOE Demonstration, Component Development & Integration Facility, Montana Media: soils and sludge Contaminants: organics and metals Details: **Field demonstration**; Waste stream fed into sealed plasma centrifuge furnace and heated to 2800-3000°F; Organics were evaporated leaving metals in vitrified mass	34, (1994)

A. SOIL, SEDIMENT, AND SLUDGE

3.b. THERMAL TREATMENTS: *EX SITU*

OTHER THERMAL TREATMENTS

Treatment Technology	Cost Elements	Cost	Site Characteristics/Comments	Reference
Pyrolysis	Total cost/unit	$290/metric ton ($265/ton)	Wide Beach Superfund Site, New York Media: soils Contaminants: 5000 ppm PCB Details: Aerobic thermal processor; Indirectly heated rotary kiln; Remediated to <2 ppm	35, (1994)
Cyclone furnace	Total cost/unit	$528/ton	EPA Demonstration, Babcock & Wilcox Site, Ohio Media: soil Contaminants: organics and metals Details: **Field demonstration**; Soils were excavated; Waste stream entered furnace and contacted a swirling air/fuel mixture operating at 820°F; Produced a volcanic glass product similar to ISV	36, (1994)
Molten salt oxidation	Total cost/unit	$500/ton	DOE Demonstration, Energy Technology Engineering Center, Oak Ridge National Laboratory, Tennessee Media: Liquid wastes and solids Contaminants: radionuclides, organics, oils, graphite, chemical warfare agents, and explosives Details: **Field demonstration**; Waste stream passes through sparged bed of turbulent molten salt; Operated at 800 to 1000°C with 2 sec. residence time; Off-gas filtered before release	37, (1994)

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A. SOIL, SEDIMENT, AND SLUDGE

4. OTHER TREATMENTS

A. SOIL, SEDIMENT, AND SLUDGE

4.a. OTHER TREATMENTS

EXCAVATION

Treatment Technology	Cost Elements	Cost	Site Characteristics/Comments	Reference
Excavation	Excavation Chemical analysis Haz. waste disposal Haz. waste treatment Conventional waste disposal Mixed waste treatment Mixed waste disposal Radioactive waste disposal	$100/yd^3 $4000 $200/ton $140/ton $65/ton $2750/ton $1014/ton $1600/ton	Santa Susan Field Laboratories, Rocketdyne Division, Rockwell International, San Fernando Valley, California Media: 11,400 yd^3 soil Contaminants: VOCs, alkali metals, SVOCs, pesticides, PCBs, chlorinated solvents Details: Mixed waste treatment by thermal X-TRAX process; Processed 75 yd^3/day; 170 miles to hazardous waste disposal facility; Radioactive waste disposed of by burial in containers	1, (1994)
Excavation	60 x 160 x 26 ft. enclosure Air exhaust control system Foam vapor suppressants Excavation (18 days) Tar processing Air monitoring Total	$70,976 $40,415 $89,591 $82,512 $17,367 $100,160 $401,021 ($1685/yd^3)	McColl Superfund Site, Fullerton, California Media: 137 yd^3 waste (mud, tar, char); 101 yd^3 overburden Contaminants: black asphalt waste; benzene, toluene, ethylbenzene, xylenes; 1000 ppm SO_2 in air emissions; 492 ppm THC Details: **Trial excavation for purpose of testing enclosure**; Enclosure had exhaust treatment system, tar processing, and air monitoring; Operated for 18 days; NaOH wet scrubber and GAC to treat emissions	2, (1992)

A. SOIL, SEDIMENT, AND SLUDGE				
4.a. OTHER TREATMENTS				
EXCAVATION, continued				
Excavation	Capital cost O&M Present worth	$1.27 million $576,000 total $1.85 million *($45/yd^3)*	Loring Air Force Base Quarry Site, Operable Unit 7, Limestone, Maine Media: 28,000 yd^3 soil, sediments of quarry, 15,000 yd^3 contaminated debris Contaminants: total PAHs range from 1.0 to 50 mg/kg; TPH max. conc. 16,000 ppm Details: Air Force Base closure in Sept. 1994; Quarry site is 7 acres, covered with construction waste material; Remediation included site prep, excavation of lower and upper tier soil and drainage ditch sediments; Use of excavated materials as low-grade fill on base; Wetlands restoration; Environmental monitoring and 5 yr. site review	3, (1994)

4.b. OTHER TREATMENT REFERENCES

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B. GROUNDWATER AND SURFACE WATER

1. BIOLOGICAL TREATMENTS

B. GROUNDWATER AND SURFACE WATER

1.a. BIOLOGICAL TREATMENTS: *IN SITU*

IN SITU BIOREMEDIATION

Treatment Technology	Cost Elements	Cost	Site Characteristics/Comments	Reference
In situ bioremediation	Treatment cost/unit (includes capital and pre-treatment; does not include site prep, excavation, waste handling, residual disposal, or permitting)	$31.25/1000 gal.	West Wago, Louisiana Media: 4 million gallons sludge and process water Contaminants: 20,000 ppm oil and grease Details: One acre lagoon, 75% surface area covered with waxy sludge; Surface aerators installed in lagoon for aeration and mixing in situ; Lagoon inoculated with selected bacterial strains; Biodegradation took one year to reach 15 ppm for oil and grease	1, (1994)
Nitrate-enhanced bioremediation	Total treatment cost	$650,000	Park City Pipeline Superfund Site, Park City, Kansas Media: groundwater Contaminants: petroleum, benzene Details: Full-scale operation since December 1992; Ammonium chloride and nitrate amendments to stimulate microbial activity; Benzene concentration in aquifer reduced to 5 ppb	2, (1994)
Oxygen-enhanced bioremediation	Total treatment cost	$274,000 (1990)	New York State Department of Conservation UST Site Media: soil, groundwater Contaminants: 10 ppm BTEX Details: 6 monitoring wells to track movement of plume; Infiltration gallery installed at former UST location with purge well taking up contaminated groundwater; In situ aquifer bioremediation with nutrient and H_2O_2 amendments; Reduced concentrations to 1 ppb BTEX in groundwater and 50 ppb in surrounding soil	3, (1994)

B. GROUNDWATER AND SURFACE WATER				
1.a. BIOLOGICAL TREATMENTS: *IN SITU*				
IN SITU BIOREMEDIATION, continued				
Oxygen-enhanced bioremediation and soil flushing	Total treatment cost including capital and O&M	$1,191,000	Union Pacific Railroad, Pocatello, Idaho Media: upper aquifer groundwater, soil Contaminants: NAPLs Details: Groundwater extracted from 11 wells at 20 gpm each; Process equipment included recovery wells, treatment system, and infiltration galleries; Treated water enhanced with O_2 and nutrient amendments to stimulate in situ biodegradation during soil flushing; Treated 439 million L/yr. (116 million gal./yr.) for five years.	4, (1993)
Nitrate-enhanced bioremediation	Total cost/unit	$160 to $230/gal. fuel removed	Air Force Demonstration, Eglin Air Force Base, Florida Media: groundwater Contaminants: jet fuel (toluene, xylene, ethylbenzene) Details: **Field demonstration**; Anaerobic nitrate-enhanced in situ biodegradation	5, (1994)
In situ bioremediation	Total treatment cost	$2 million *($4/gal.)*	Seymour Recycling Superfund Site, Operable Unit 1, Indiana Media: 500,000 gal. groundwater Contaminants: vinyl chloride, TCE, DCE, benzene, chloroethane Details: Full-scale remediation began in June 1991 with expected completion in 1996; In situ bioremediation for vinyl chloride, TCE, and DCE; Vacuum extraction and chemical treatment for other contaminants	6, (1991)

B. GROUNDWATER AND SURFACE WATER

1.a. BIOLOGICAL TREATMENTS: *IN SITU*

IN SITU BIOREMEDIATION, continued

Nitrate-mediated bioremediation	Unit costs for remediation	$84/gal. JP-4 $200/$m^3$ JP-4 contaminated groundwater $17/$m^3$ groundwater down to confining layer	UST Site, US Coast Guard Facility, Traverse City, Michigan Media: 2,640,000 gal. groundwater Contaminants: JP-4 jet fuel (primarily BTEX and free product) Details: **Field demonstration**; 4 large USTs leaking JP-4; Anaerobic degradation of organics through nitrate reduction; Fuel-contaminated groundwater biodegradation initiated through infiltration gallery in 900 ft^2 area with series of interdiction wells equipped with free product recovery pumps and 9 cluster wells for monitoring; Nitrates and nutrients batch-mixed and introduced via chemical feed pumps; Recirculating water between gallery/contaminated zone and purge wells created an in situ bioreactor; Cost evaluation pro-rates construction costs over a 5 yr. period; Unit costs found by dividing cost for construction, labor, chemicals, and electricity by volume of JP-4 under infiltration gallery	7, (1994)
In situ bioremediation of water plus solid-phase bioremediation of soil	Total treatment cost	$11 million	Burlington Northern Railroad Superfund Site, Somers, Montana Media: groundwater; 12,000 yd^3 excavated soil; 70,000 yd^3 soil in situ Contaminants: PAHs, zinc, and phenol in soil; PAHs in groundwater Details: Operational early 1993 with 5 to 10 yr. completion time; 12,000 yd^3 excavated soil undergoing solid-phase bioremediation; Groundwater being treated with in situ bioremediation; Soil concentration target is 36 μg/kg PAHs and groundwater target is 0.030 μg/L PAHs; Soil also treated with in situ soil flushing	8, (1991)

B. GROUNDWATER AND SURFACE WATER

1.b. BIOLOGICAL TREATMENTS: *EX SITU*

SLURRY-PHASE BIODEGRADATION/BIOREACTORS

Treatment Technology	Cost Elements	Cost	Site Characteristics/Comments	Reference
Fixed-film bioreactor, in situ aquifer treatment, and land treatment of soils	Total remediation costs including pilot and full-scale operations	$8 to $10 million	Libby Groundwater Superfund Site, Libby, Montana Media: screened soil and rock totaling 75,800 yd^3; groundwater plume extending approx. 1 mile in length Contaminants: >5000 mg/kg PCPs Details: 4 existing monitoring wells used for in situ bioremediation; H_2O_2 injection system with new monitoring and extraction wells drilled; Groundwater recovery with 2 fixed-film bioreactors; 2 land treatment units for contaminated soil, each 1 acre in size with a capacity of 25,000 yd^3; Operational period of 6 yrs. for soil and <10 yrs. for aquifer treatment to obtain target concentrations of >100 mg/kg; Costs are min. and max. estimates	9, (1994)
Slurry-phase bioreactor following soil washing	Treatment cost/unit (including water treatment, slurry biodegradation, and incineration)	$168/ton (1989)	Macgillis and Gribbs Site, New Brighton, Minnesota Media: soils Contaminants: PAHs, PCP, Cu, Cr, As Details: **SITE Program demonstration**; Biotrol, Inc. soil washing process for volume reduction; Fixed-film bioreactor to treat process water ex situ; Slurry bioreactor to treat soil washing residuals; Incineration of woody debris; Soil washing removed 87 to 89% PCP and 83 to 88% PAHs; Bioreactor removed 91 to 94% PCP	10, (1993)

B. GROUNDWATER AND SURFACE WATER				
1.b. BIOLOGICAL TREATMENTS: *EX SITU*				
SLURRY-PHASE BIODEGRADATION/BIOREACTORS, continued				
Fixed film bioreactor	Total treatment cost (expected)	$5 to $6 million	New Lyme Landfill Superfund Site, New Lyme, Ohio Media: groundwater Contaminants: ethylbenzene, methylene chloride Details: Pilot scale study conducted on Jan. 1988; Full-scale remediation began Nov. 1991; Used rotating fixed film reactors; 100% of groundwater under bioremediation; Calcium carbonate precipitation caused plugging; Remediation levels are 68 µg/L ethylbenzene, 473 µg/L methylene chloride, and 9.2 µg/L phthalate; Costs are min. and max. estimates	11, (1991)
Sequencing batch bioreactor	Total treatment cost (expected)	$15 million	Reilly Tar and Chemical Corporation Superfund Site, Indiana Media: groundwater Contaminants: benzene, ammonia, pyridine Details: Remediation began Dec. 1991; Groundwater sequencing batch reactor with continuous flow; 100% of groundwater under bioremediation; 60 to 80 ft. aquifer with conductivities of 10^{-2}; 1.6 mgd extraction system	12, (1991)
Fixed film bioreactor	Start-up costs	$100,000	Conservation Chemical Superfund Site, Kansas City, Missouri Media: groundwater Contaminants: phenols, VOCs, SVOCs Details: Full-scale remediation started April 1990; Using aerobic attached growth process with 2 fixed film bioreactors in series; Treatment train also included carbon adsorption, lime precipitation, and sulfide precipitation; Bioreactor operating at 150 to 200 gpm for approx. 30 yrs.	13, (1991)

B. GROUNDWATER AND SURFACE WATER				
1.b. BIOLOGICAL TREATMENTS: *EX SITU*				
SLURRY-PHASE BIODEGRADATION/BIOREACTORS, continued				
Bioreactor	Total cost/unit	$0.50/gal.	DOE Demonstration, Savannah River Site, Aiken, South Carolina Media: groundwater Contaminants: TCE, PCE 1000 ppb Details: **Field demonstration**; Aquifers must be homogenous; Used methanotropic fluidized bed and trickle filter bioreactor; 90% TCE/PCE removal efficiency; Cu content in water may have inhibited biodegradation	14, (1994)
Bioreactor plus in situ bioremediation of soil	Total project cost	$91,700	Naval Air Warfare Center, Lakehurst, New Jersey Media: soil below lagoon; groundwater in 180 ft. x 45 ft. contaminant plume Contaminants: ethylene glycol up to 4900 ppm in soil and up to 2100 ppm in groundwater Details: First phase used injection system for in situ biodegradation by adjusting pH, providing O_2 and nitrogen/phosphate amendments; 5 recovery wells pumped contaminated groundwater into bioreactor with reinjection into vadose zone after treatment; Avg. flow rate in closed loop = 20 gpm; Lagoon injection system flushed contaminated soil and forced contaminated water to 1 of 3 recovery wells installed in lagoon; 435 day treatment lowered contaminants to non-detect levels	15, (1994)

B. GROUNDWATER AND SURFACE WATER				
1.b. BIOLOGICAL TREATMENTS: *EX SITU*				
SLURRY-PHASE BIODEGRADATION/BIOREACTORS, continued				
Bioreactor treatment of water plus land treatment and soil flushing	Land treatment: Capital O&M Soil flushing: Capital O&M Water treatment: Capital O&M Present worth	$905,598 $126,509/yr. $5,483,950 $58,070/yr. $1,252,725 $744,211/yr. $9,074,062 (1992)	Idaho Pole Company Superfund Site, Bozeman, Montana Media: 19,000 yd^3 soil and sediment; 23,000 yd^3 soil in situ; 210 mil. gal. groundwater Contaminants: PCP up to 25 mg/kg; benzo(a)pyrene up to 1.7 mg/kg; dioxins/furans up to 34.2 µg/kg Details: Former wood treating site; Excavated soil pretreated with oil/H_2O separator to remove creosote (to be recycled and/or disposed of off-site); Excavated soils treated in land treatment unit covering 4 acres with 1 ft. deep unit layers; When completed, land treatment unit will be closed by capping; Clean fill to replace excavated soil; Inaccessible soils treated by hot water/steam flushing and enhanced in situ bioremediation with O_2 and nutrient amendments; Groundwater extracted and treated in bioreactor; Reinjection of treated water to stimulate in situ bioremediation	16, (1992)
Fixed film bioreactor plus land treatment of soil	Total treatment cost (expected)	$3.5 million	JH Baxter Superfund Site, Weed, California Media: groundwater; 21,875 yd^3 soil Contaminants: As, Cr, Zn, PCP, PAHs, dioxin/furans Details: Excavated soil with organics (12,500 yd^3) treated in prepared bed land treatment unit; Soil with mixed organic-heavy metal contamination needs further treatment; Groundwater pumped and treated in fixed film bioreactor; Start-up March 1993	17, (1991)

B. GROUNDWATER AND SURFACE WATER				
1.b. BIOLOGICAL TREATMENTS: *EX SITU*				
ACTIVATED SLUDGE				
Activated sludge	Total treatment cost	$2.5 million/yr.	Sylvester Superfund Site, Nashua, New Hampshire Media: groundwater Contaminants: phenols, MEK, acetone, toluene, benzene, vinyl chloride, chloroform Details: Full-scale remediation started June 1986 and completed July 1994; Activated sludge biotreatment of groundwater with extended aeration; Vacuum extraction used in vadose zone; Air stripping operated at 3000 gpm and activated sludge operated at 50 gpm; Remediated to New Hampshire safe drinking water standards; 8 yr. total time	18, (1991)

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B. GROUNDWATER AND SURFACE WATER

2. PHYSICAL AND CHEMICAL TREATMENTS

B. GROUNDWATER AND SURFACE WATER

2.a. PHYSICAL/CHEMICAL TREATMENTS: *IN SITU*

GROUNDWATER SPARGING/STRIPPING

Treatment Technology	Cost Elements	Cost	Site Characteristics/Comments	Reference
Groundwater stripping with thermally-enhanced SVE	Capital O&M for 1000 gpm system	$4.3 million $630,000/yr.	Lockheed Aeronautical Systems, Burbank, California Media: groundwater, soil Contaminants: 2.2 ppm TCE and 11 ppm PCE in groundwater; 6000 ppm VOCs in soil (soil gas) Details: Integrated groundwater stripping and soil system; Running at 1000 gpm; Removal of 98 to 99.9% VOCs	1, (1994)
Air Sparging and SVE	Initial pilot study Treatment system O&M ($1500/mo. for 6 mos.) Electricity ($600/mo. for 6 mos.) Total	$90,000 $165,000 $9000 $3600 $267,000 (1995)	UST Site, Big Rapids, Michigan Media: 43,200 ft^2 contaminated area Contaminants: VOCs (12% concentration); free product floating on surface water and in groundwater Details: Site contains 5 leaking USTs and gasoline lines; Air sparging provides in situ removal of dissolved VOCs from groundwater; Vacuum extraction used during air sparging to control and capture stripped contaminants in the sparge area; Automated Soil Vent Trailer (ASVT) with Shallow Tray® H_20 treatment system; 7 vapor extraction wells and 15 air sparging wells plus 640 ft. of trenching to connect VE and SP wells; GAC to treat off-gas	2, (1995)

B. GROUNDWATER AND SURFACE WATER

2.a. PHYSICAL/CHEMICAL TREATMENTS: *IN SITU*

GROUNDWATER SPARGING/STRIPPING, continued

Density-driven groundwater sparging with SVE	Capital costs: Drill/install wells Install VE system Sparging system Electrical connections Trenching, backfilling Air compressor Start-up Project mang. Total capital Operating costs: Main. labor and parts Monitoring/reporting Elec. ($.07/kWhr) Total annual operating	 $16,000 $40,300 $25,750 $4050 $26,800 $26,800 $3000 $10,000 $156,950 $30,000 $30,000 $2750 $62,750/yr. (1993)	Amcor Precast, Ogden, Utah Media: groundwater plume approximately 30,000 ft^2; 7500 yd^3 soil Contaminants: 190 mg/L TPH, 4.7 mg/L benzene, 9.4 mg/L toluene, 8.0 mg/L xylenes, 0.63 mg/L naphthalene, 2.7 mg/L ethylbenzene max. in groundwater; 1600 ppm TPH, 2.5 ppm toluene, 19 ppm ethylbenzene, 110 ppm xylenes, 7.8 ppm benzene max. in soil Details: Full-scale remediation of groundwater contaminated with diesel and gasoline fuels; 13 groundwater sparging wells at 18 ft.; 3 down-gradient extraction wells at 20 ft.; 3 vertical extraction wells; In situ density-driven groundwater sparging, groundwater recirculation, and SVE; 6 groundwater monitoring wells	3, (1994, 1995)
Dynamic underground stripping	Total treatment cost (process monitoring, subsurface wells, steam generation, electric heating, above-ground treatment, utilities, labor, materials) Before treatment (project mang., site characterization) Total cost (including R&D)	$5.4 million $1.7 million $10,440,000 (1993)	Gasoline Spill Site, Lawrence Livermore National Laboratory, Livermore, California Media: 100,000 yd^3 soil; groundwater in 800 acre site Contaminants: 17,000 gallons leaded gasoline; BTEX and fuel hydrocarbons Details: **Commercial scale field demonstration** of dynamic underground stripping; Gasoline leaked from USTs; 6 steam injection/electric heating wells at 145 ft., 3 electric heating wells at 120 ft., and 1 vacuum extraction well at 155 ft.	4, (1995)

B. GROUNDWATER AND SURFACE WATER				
2.a. PHYSICAL/CHEMICAL TREATMENTS: *IN SITU*				
GROUNDWATER SPARGING/STRIPPING, continued				
Groundwater Sparging	Total capital cost (estimate)	$70,000 to $100,000 (1991)	Navy Demonstration, Seal Beach Navy Weapons Station, California Media: groundwater Contaminants: VOCs Details: **Field demonstration**; Injection and extraction wells placed within and outside of plume; Waste air stream fed to internal combustion engine for destruction; Air permits may be required depending on site; Costs are min. and max. estimates	5, (1994)
In-situ air stripping with horizontal wells	Equipment cost (design, engineering, well installation, air injection/extraction, piping, electrical) Site cost (set-up and level) Labor Consumables Horizontal well installation	$253,525 $5000 $62,620/yr. $157,761/yr. $50 to $200/ft.	DOE Demonstration, Savannah River Site, Aiken, South Carolina Media: aquifer and saturated zone under settling basin Contaminants: TCE, PCE, TCA; VOCs as high as 5000 ppm; TCE >48 ppm Details: **Full-scale field demonstration**; 139 day demo removed 16,000 lbs. VOCs; 7 horizontal wells installed; 2 used in field demonstration with one in the saturated zone and one in the vadose zone; Air injection below aquifer with air extraction above; Extracted avg. of 110 lbs. VOCs/day and reduced TCE and PCE to <300 ppm; Projected costs based on full-scale demo and do not include treatment of off-gas	6, (1995)

B. GROUNDWATER AND SURFACE WATER

2.a. PHYSICAL/CHEMICAL TREATMENTS: *IN SITU*

BARRIER TECHNOLOGIES

Treatment Technology	Cost Elements	Cost	Site Characteristics/Comments	Reference
Continuous permeable wall	Total capital	$720,000 (1994)	Former Semiconductor Manufacturing Facility, Sunnyvale, California Media: groundwater Contaminants: TCE, cis-DCE, vinyl chloride with influent concentrations of 210 ppb, 1.415 ppb, and 540 ppb, respectively Details: Full-scale in situ treatment wall; Reactive zone 4 ft. wide, 40 ft. long, 20 ft. deep; Contains 220 tons 100% granular Fe; Flanked by slurry walls on either side, one 225 ft. long, one 250 ft. long to direct groundwater into permeable section; Reactive iron is significant component of installation costs; Other than groundwater monitoring, the major factor affecting O&M is possible periodic removal of precipitate from Fe	7, (1996)
Continuous permeable wall	Total capital (includes $30,000 for Fe)	$250,000 (1995)	Industrial Facility, New York Media: shallow aquifer groundwater Contaminants: up to 300 ppb TCE, up to 500 ppb cis-DCE, and up to 80 ppb vinyl chloride Details: **Pilot scale**; 12 ft. long, 3.5 ft. wide central reactive section flanked by 15 ft. sheet piling extended laterally; Installation keyed into clay layer at 15 ft. below surface; VOCs reduced to MCLs within 1.5 ft. after diffusion through wall; Velocity of flow through wall is 1 ft./day capturing a 24 ft. wide plume; Used 45 tons Fe	8, (1996)

B. GROUNDWATER AND SURFACE WATER				
2.a. PHYSICAL/CHEMICAL TREATMENTS: *IN SITU*				
BARRIER TECHNOLOGIES, continued				
Funnel and gate	Installation costs	$400,000 (1996)	Industrial Facility, Kansas Media: groundwater Contaminants: 100 to 400 ppb TCE Details: **Pilot scale**; 1000 ft. funnel and gate system; 490 ft. funnel on either side of a 20 ft. long gate; Low natural groundwater velocity increased with funneling; Reactive zone between 17 and 30 ft. below surface with flow-through thickness of 3 ft.; Funnel consisted of soil-bentonite slurry wall; 70 tons granular Fe at gate section	9, (1996)
Hanging wall reactive barrier	Installation cost	$300,000 to $350,000	Former Chrome Plating Facility, US Coast Guard Support Center, Elizabeth City, North Carolina Media: groundwater Contaminants: hexavalent chromium, Cr(VI) Details: **Field test**; Hanging wall reactive barrier installed with hollow stem auger to mix sand into excavated aquifer zone soil; Mixture replaced and hanging wall installed with columns of Peerless Fe; Wall is 50 m long, 8 m deep, and 0.6 m thick; 12 monitoring wells from 12 to 24 ft.; 9 compliance wells; Full-scale start-up on June 22, 1996; O&M minimal with exception of multi-layer sampling	10, (1996)

B. GROUNDWATER AND SURFACE WATER				
2.b. PHYSICAL/CHEMICAL TREATMENTS: *EX SITU*				
OXIDATION				
Treatment Technology	**Cost Elements**	**Cost**	**Site Characteristics/Comments**	**Reference**
POWWER™ evaporation and catalytic oxidation	Total cost/unit	$110/1000 gal.	EPA Demonstration; Lake Charles Treatment Center, Louisiana Media: groundwater and waste water Contaminants: VOCs, non-volatile organics, salts, metals Details: **Demonstration** of 0.25 gpm pilot plant; Concentrated residual solution of contaminants required disposal or further treatment	11, (1994)

B. GROUNDWATER AND SURFACE WATER

2.b. PHYSICAL/CHEMICAL TREATMENTS: *EX SITU*

FILTRATION/SEPARATION

Treatment Technology	Cost Elements	Cost	Site Characteristics/Comments	Reference
Filtration	Operation cost	$500,000 to $1,200,000/yr.	American Creosote Works, Pensacola, Florida Media: groundwater Contaminants: PAHs, smaller phenolics Details: Positive pressure membrane hyperfiltration unit; 95% removal of PAHs	12, (1994)
Filtration	Operation cost	$213,000 to $549,000/yr.	Palmerton Zinc Superfund Site, Palmerton, Pennsylvania Media: groundwater Contaminants: zinc, TSS Details: Pressure membrane microfiltration; Shallow aquifer with dissolved heavy metals	13, (1994)
Filtration	Capital cost Total cost/unit	$150,000 $0.40 to 0.$53/1000 L ($1.50 to $2.00/1000 gal.)	DOE SITE Demonstration, Rocky Flats, Golden, Colorado Media: groundwater Contaminants: 40 to 100 mg uranium/L H_2O at filtration system intake Details: **Commercial scale SITE demonstration**; Colloid sorption filter for metals and non-tritium radionuclides; 58 to 95% removal of uranium	14, (1994)

B. GROUNDWATER AND SURFACE WATER				
2.b. PHYSICAL/CHEMICAL TREATMENTS: *EX SITU*				
FILTRATION/SEPARATION, continued				
Filtration	Capital cost O&M cost	$150,000 $1.50 to $2.00/1000 gal.	EPA and DOE Co-Demonstration, Rocky Flats Facility, Colorado Media: water Contaminants: heavy metals and non-tritium radionuclides (NORM, LLRW, TRU) Details: **Field demonstration**; "Polishing" filtration process for heavy metals, NORM, LLRW, and TRU; Used sorption, chemical complexing, and hydroxide precipitation; Created a concentrated waste sludge	15, (1994)
Membrane separation	Total cost/unit	$228 to $1739/1000 gal. (1991)	EPA Demonstration, American Creosote Works, Florida Media: groundwater Contaminants: PAH, creosote, smaller phenolics Details: **Field demonstration**; Removed 90% PAHs and 80% creosote; Used hyperfiltration unit; Concentrated contaminants were directed to holding tank	16, (1994)

B. GROUNDWATER AND SURFACE WATER

2.b. PHYSICAL/CHEMICAL TREATMENTS: *EX SITU*

PUMP AND TREAT

Treatment Technology	Cost Elements	Cost	Site Characteristics/Comments	Reference
Pump and treat with air stripping	Total cost/unit	$0.20/1000 L ($0.75/1000 gal.)	DOE Savannah River Site, Aiken, South Carolina Media: groundwater Contaminants: 15 ppm TCE, 6.7 ppm PCE Details: 500 gpm air stripper; 11 wells; Reduced levels in water to < 1 ppm TCE and PCE	17, (1994)
Pump and treat with GAC	Capital cost (system design, construction, site work, equipment, mobilization/ demobilization) Operating cost (carbon regeneration, maintenance, lab, project mang.)	$958,780 $129,400/yr. (1994)	Fort Drum Fuel Dispensing Area 1595, Watertown, New York Media: groundwater Contaminants: BTEX, free petroleum product Details: UST site with 10 dispensing units; Pump and treat with 2 recovery wells at 25 ft. and 5 to 6 gpm; Oil/H_2O separator, air stripper, GAC; Free product recovery pumps required frequent maintenance; GAC efficiency limited by Fe and biomass build-up	18, (1995)
Pump and treat	Capital costs (demolition, excavation, system installation, start-up, mobilization, site prep) Operating costs (labor, materials, equipment)	$569,739 $216,561 (1993) $143,047 (1994)	Langley Air Force Base, Aviation R & D Facility, Virginia Media: 2 million ft^2 groundwater aquifer; 180,000 ft^2 area of surrounding soil Contaminants: BTEX; TPH >100 ppm in soil, max. 4100 ppb in water; free product Details: UST site with 24 25,000 gal. tanks; Full-scale remediation of fuel-oil contaminated groundwater using vacuum assisted well-point extraction and aboveground air stripping; Pump and treat with vacuum-assisted well point extraction system, oil/H_2O separators, and air strippers; Extraction network average flow rate of 32 gpm; 2 air stripper columns	19, (1995)

B. GROUNDWATER AND SURFACE WATER				
2.b. PHYSICAL/CHEMICAL TREATMENTS: *EX SITU*				
PUMP AND TREAT, continued				
Pump and treat with thermal oxidation and GAC	Incinerator, air stripper, scrubber, wells, GAC Heat exchanger, pumps, compressors, control center Total capital cost Operating cost (contractor, utilities, operations, sampling/ analysis, project mang.)	$1.7 million $1.0 million $4.0 million $1,240,000/yr. (1993)	Superfund Site Operable Units B/C, McClellan Air Force Base, Sacramento, California Media: 660 mil. gal. groundwater Contaminants: VOCs, primarily TCE, DCE, PCE, and DCA; avg. 60 ppm Details: 7 extraction wells into main treatment plant; Air strippers (250 gpm) used thermal oxidation and caustic scrubbing; Two GAC units for liquid phase prior to discharge; 44,000 lbs. VOCs removed	20, (1995)
Pump and treat	Capital cost (construction of treatment plant, wells, force main, pump houses, start-up, engineering, project mang.) Operating cost (power, labor, tower packing, maintenance, lab) Total life cycle costing Total O&M	$8,034,454 $588,599/yr. (1992) $0.30/1000 gal. $0.12/1000 gal.	Twin Cities Army Ammunition Plant, New Brighton, Minnesota Media: groundwater Contaminants: VOCs including DCE, DCA, TCA, TCE, and PCE; TCE most prevalent at 10,000 ppb Details: 14 source areas; Groundwater extraction by 12 boundary recovery wells and 5 source area recovery wells; Air stripper operating at 2900 gpm with four 36 ft. tall towers packed with propylene; Treated water discharged to sand/gravel pit; Boundary Groundwater Recovery System (BGRS) recovered an avg. of 23 lbs. VOCs/day; Estimated 92,700 lbs. VOCs have been recovered in 6 yrs.	21, (1995)

B. GROUNDWATER AND SURFACE WATER				
2.b. PHYSICAL/CHEMICAL TREATMENTS: *EX SITU*				
PUMP AND TREAT, continued				
Pump and treat with oxidation	Capital cost (equipment, site prep, construction, start-up, engineering) Operating cost (maintenance, project management, lab analysis, supplies)	$1,383,400 $355,200/yr. (1994)	US DOE Kansas City Pant, Kansas City, Missouri Media: groundwater Contaminants: chlorinated VOCs, aromatic VOCs, PCBs, metals, TCE >10,000 μg/L; DNAPLs suspected Details: Pump and treat with Advanced Oxidation Process; 14 extraction wells; Extracted water initially treated by low-intensity UV/O_3/H_2O_2 treatment; Later replaced with high intensity UV/H_2O_2 system eliminating need for GAC and reducing O&M; 11.2 mil. gal. treated as of 1993	22, (1995)
Pump and treat	Capital cost (design, construction, installation, engineering, site development) Operating cost (electricity, maintenance, well sampling/analysis) Total O&M	$4,103,000 $149,200/yr. $0.75/1000 gal.	US DOE Savannah River Site, Aiken, South Carolina Media: groundwater beneath settling basin Contaminants: 25,000 ppb TCE, 12,000 ppb PCE, VOCs as high as 500 ppm; DNAPLs present in groundwater Details: Area is 150 ft. deep, covering 1200 acres; 11 recovery wells at 200 ft.; 510 gpm production air stripper; Avg. air emission rate of 2 lbs./hr.; Supplemental site characterization to define DNAPL contamination may alter costs; Operating at 198 million gal./yr.	23, (1995)
Pump and treat	Total treatment cost	$600 million	Tokol Airbase, Budapest, Hungary Media: 3 million m^3 soil; 1 million m^3 groundwater Contaminants: TPH; 6000 m^3 free product in H_2O Details: Former Soviet military base; Aquifer at 4 to 5 m depth with plume affecting municipal well field; Free product separated from groundwater by depressing water table to speed flow to extraction wells; Pumping and on-site oil/H_2O separation; Recovered 224,000 L free product and 700,000 L jet fuel	24, (1995)

B. GROUNDWATER AND SURFACE WATER				
2.b. PHYSICAL/CHEMICAL TREATMENTS: *EX SITU*				
PUMP AND TREAT, continued				
Pump and treat with fluidized bed reactor	Air stripping Catalytic oxidation Purchase price of oxidation unit	$3.19/1000 gal. $1.70/1000 gal. $113,000 (1992)	UST Site, Wurtsmith Air Force Base, Oscoda, Michigan Media: groundwater; plume is 9,000,000 m^3 Contaminants: TCE max. 10,000 µg/L; benzene Details: Pumped groundwater fed through a 200 gpm packed bed air stripper; Catalytic oxidation used for emissions control with fluidized bed reactor; Operating temp. is 700°F with a 97% DRE for TCE	25, (1993)
Pump and treat with solids removal and air stripping	Capital costs: Impermeable cover Groundwater treatment Design, supervision, admin., and 30% contingency Total capital O&M Present worth (5%, 35 years, ROD estimate)	 $285,000 $447,000 $251,000 $983,000 $74,000 - 105,000/yr. $2.25 million *($0.05/gal.)*	Hellertown Manufacturing Superfund Site, Northampton County, Pennsylvania Media: 49 mil. gal. groundwater Contaminants: max. conc. in groundwater: 83 µg/L vinyl chloride, 1700 µg/L TCE, 260 µg/L 1,2-DCE, 22 µg/L PCE Details: Installation of 2 ft. thick impermeable clay cover over soil-filled former lagoon area; Capped with topsoil and reseeded; Routine monitoring and maintenance of cover; Installation of stormwater catchment system; Pump and treat extracted groundwater; Solids removed by settling tank; Filtration/ treatment with air stripping and GAC; Discharge to nearby creek; Long-term groundwater monitoring for 30 to 40 years with 23 monitoring wells; Total O&M depends on length of monitoring	26 (1991)

B. GROUNDWATER AND SURFACE WATER

2.b. PHYSICAL/CHEMICAL TREATMENTS: *EX SITU*

PUMP AND TREAT IN CONJUNCTION WITH OTHER REMEDY

Treatment Technology	Cost Elements	Cost	Site Characteristics/Comments	Reference
In situ air sparging plus pump and treat with GAC	Groundwater treatment (well construction, pumps, installation, engineering) Air sparging system (3 mos. initial operation and testing) Operating cost (pump and treat only)	$297,000 $375,000 $475,600/yr. (1994)	Amoco Petroleum Pipeline, Constantine, Michigan Media: 775 mil. gal. groundwater Contaminants: gasoline, fuel oil, kerosene, free product (approx. 350,000 to 2,000,000 gal.) Details: Pump and treat with 4 extraction wells at 28 ft.; GAC used to recover free product; In situ air sparging to treat saturated zone with 30 2-inch diameter wells from 25 to 30 ft.	27, (1995)
Incineration plus pump and treat with GAC	Total treatment cost (ROD estimate)	$47.5 million	Texarkana Wood Preserving Company Superfund Site, Bowie County, Texas Media: 77,000 yd^3 soil, affected sediments, and sludges; 16 mil. gal. contaminated groundwater Contaminants: creosote, dioxin, PAHs, pesticides, phenols including PCP Details: 25 acre site; Excavation and incineration of soils, sediment, and sludges near processing ponds; On-site backfilling of ash, capping, and revegetation; Pump and treat shallow groundwater with GAC; Reinjection of treated water on-site; Clean-up levels are 3 ppm carcinogenic PAHs, 2350 ppm total PAHs, 150 ppm PCP, and 20 ppb combined dioxins and furans	28, (1995)

B. GROUNDWATER AND SURFACE WATER				
2.b. PHYSICAL/CHEMICAL TREATMENTS: *EX SITU*				
PUMP AND TREAT IN CONJUNCTION WITH OTHER REMEDY, continued				
Rotary kiln incineration plus pump and treat with GAC	IT Corp. contract (source control, air quality mang., site prep, dredging, excavation, bank stabilization, mobilization/demob., trial burn, incineration, and site closure)	$110 million	Bayou Bonfouca Superfund Site, Slidell, Louisiana Media: groundwater; 150,000 yd^3 (114,685 m^3) total sediment; 157,000 tons soils and solids Contaminants: creosote; PAHs 15,680 mg/kg at surface; ≤ 2488 mg/kg contamination in shallow aquifer soils Details: Pump and treat groundwater from 3 plumes; Clean effluent directed back to bayou; Oil/H_2O separation, filtration, carbon bed adsorption, aeration; Excavation of surface soils, waste piles; Dredge/dewater bayou sediment; Incineration with ash deposited in on-site landfill; Costs do not include long-term pump and treat	29, (1994)
SVE plus pump and treat with GAC	Total capital cost (contract amount)	$1,343,000 (1993)	Commencement Bay, South Tacoma Channel Well 12A Superfund Site, Phase 2, Tacoma, Washington Media: 281,700,000 gal. groundwater Contaminants: chlorinated hydrocarbons, DCE, PCA (209,115 lb. free phase), PCE (3734 lb. free phase), TCE (126,112 lb. free phase); PCA in groundwater >10,000 µg/L Details: Groundwater contamination in city production well; SVE used to remove VOCs from soil matrix; Upper aquifer (at 50 ft.) affected; Treated water discharged to storm drain system; 281,700,000 gallons treated as of 2/94; GAC used to treat off-gas; No information provided on operating costs, cost sensitivities, or breakdown of capital costs	30, (1995)

B. GROUNDWATER AND SURFACE WATER				
2.b. PHYSICAL/CHEMICAL TREATMENTS: *EX SITU*				
PUMP AND TREAT IN CONJUNCTION WITH OTHER REMEDY, continued				
Pump and treat groundwater with GAC plus bioreactor treatment of soil	Groundwater clean-up Soil clean-up Present worth (included $32,800 annual O&M for 5-10 yrs., ROD estimate)	$236,000 $365,000 to $448,000 $601,000 to $684,000 (1992)	Jasco Chemical Superfund Site, Mountain View, California Media: groundwater, 1100 yd^3 soil Contaminants: 2.2 ppm 1,1-DCA, 2.6 ppm 1,2-DCA, 170 ppm 1,1-DCE, 142 ppm methylene chloride, 16 ppb vinyl chloride in groundwater; 3400 ppm methylene chloride, 490 ppm trichloroethylene, 1700 ppm toluene, 270 ppm acetone in soil Details: Groundwater Treatment: On-site construction of liquid-phase carbon adsorption unit; 12 wells from 22 to 35 ft., 3 from 42 to 57.5 ft.; Plume area is 400 ft.; Treated water discharged to municipal sewer system; Continued pump and treat for 10 years; Quarterly monitoring; Soil Treatment: 1100 yd^3 excavated soil treated in bioreactor with nutrient amendments; Aerobic system with airdraw to pull off VOCs; GAC to treat air stream; Off-site disposal of soils with residual contamination; Costs are estimated min. and max.	31 (1992)
Pump and treat with GAC plus in situ SVE	Capital cost O&M Present worth (ROD estimate)	$1,951,500 $249,000/yr. $5,451,000 (1991)	Garden State Cleaners, Buena Borough, New Jersey Media: approx. 1600 yd^3 soil; 1.6 bil. gal. groundwater Contaminants: 6.1 ppm TCE, 1300 ppm PCE, 8.1 ppm acetone, 0.5 ppm methylene chloride max. in soil; 13 ppm TCE and 1.9 ppm PCE max. in groundwater Details: SVE system operating for 6 to 9 mos.; Contaminated air/water flows to air/H_2O separator; Contaminated water pumped into treatment system where air stream was treated with GAC; Estimated 70 yr. treatment for entire plume; 13 deep and 7 medium extraction wells operating at 1000 gpm; 10 injection wells for treated water	32, (1991)

B. GROUNDWATER AND SURFACE WATER				
2.b. PHYSICAL/CHEMICAL TREATMENTS: *EX SITU*				
PUMP AND TREAT IN CONJUNCTION WITH OTHER REMEDY, continued				
In situ bioremediation, incineration, and pump and treat with incineration	Bioremediation, excavation, and incineration: Capital costs O&M Present worth Pump and treat: Capital costs O&M Present worth	 $29 million $500,000/yr. $40 million (1993) $2 million $250,000/yr. $6 million (1993)	American Creosote Works Inc. Superfund Site, Winnfield, Louisiana Media: 25,000 yd^3 sludge, 250,000 yd^3 soil; shallow groundwater Contaminants: PAHs, PCP Details: Excavation and incineration of 25,000 yd^3 highly contaminated sludge and tars; Decontaminated ash used on-site as fill; Pump and separate NAPLs from sub-surface zones of pooled product to promote biodegradation of PCP and PAHs; Incineration of NAPLs and reinjection of water to promote flushing of contaminants into 250,000 yd^3 in situ biotreatment zone; O_2 and nutrients added; 30 yr. remediation	33, (1993)
In situ bioremediation and pump and treat with GAC	Capital: Soil treatment Groundwater treatment Site overhead O&M Replacement Total Present Worth (ROD estimate)	 $1,475,000 $971,000 $1,764,000 $0 $0 $4,210,000	North Cavalcade Street Site, North Cavalcade, Texas Media: 22,300 yd^3 soil; 5.6 mil. gal. groundwater Contaminants: 79 µg/L benzene, 620 µg/L toluene, 280 µg/L xylenes, 39,000 µg/L naphthalene max. in groundwater; 14,394 ppm total PAHs and 9187 ppm naphthalene max. in soil Details: 21 acre former wood-preserving operation; Clean-up levels are 1 ppm for carcinogenic PAHs in soil and 5 µg/L in groundwater; In situ bioremediation of soils with O_2 and nutrients, 3 yr. duration; On-site pump and treat of contaminated groundwater with oil/H_2O separation and carbon filtration to be completed in 2 yrs.; Selected remedy has no long-term O&M beyond 5 yrs.; Since replacement costs are those for replacing elements needed in long-term operation, and selected remedy has no long-term operation, there are no associated replacement costs	34, (1988)

B. GROUNDWATER AND SURFACE WATER				
2.b. PHYSICAL/CHEMICAL TREATMENTS: *EX SITU*				
PUMP AND TREAT IN CONJUNCTION WITH OTHER REMEDY, continued				
Land treatment of soil plus pump and treat with incineration	Biological treatment: Capital costs O&M Present worth Pump and treat: Capital costs O&M Present worth	 $11.5 million $25,000/yr. $11.9 million (1992) $1.2 million $153,000/yr. $5.3 million (1992)	Popile Inc. Site, El Dorado, Arkansas Media: 165,000 yd^3 soil and sludge; 84 mil. gal. groundwater; 750,000 pooled creosote Contaminants: ≤ 32,700 ppb benzo(a)pyrene and ≤ 280,000 ppb PCP in soil; ≤ 698 ppb benzo(a)pyrene equivalent and 460,000 ppb PCP in groundwater Details: Excavation/treatment of 165,000 yd^3 soil and sludge in land treatment unit (15-20 yr. treatment time); Extraction wells, interceptor trenches, and subsurface drains to capture pooled product and create hydraulic containment barrier; Partial slurry wall to prevent infiltration of surface water to groundwater; Removal of NAPLs with sedimentation and oil/H_2O separation; Filtration of H_2O in sand filter and activated carbon; Reinjection followed by deep in situ bioremediation for unrecoverable NAPLs with injection wells and feed system; In situ phase will cost an additional $950,000	35, (1993)
Rotary kiln incineration plus pump and treat groundwater	Thermal destruction: Capital costs O&M Present worth Pump and treat: Capital costs O&M Present worth	 $42 million $60,000/yr. $43.1 million (1990) $3.4 million $1.0 million/yr. $4.4 million (1990)	Operable Unit 1, Texarkana Wood Preserving Company Site, Texarkana, Texas Media: 77,000 yd^3 soil, sludge, and sediments; 16 mil. gal. shallow groundwater Contaminants: PCP: 1400 ppm max. in soil, 4.1 ppm max. in H_2O, 5100 ppm in sludge; benzo(a)pyrene: 1396 ppm max. in soil, 0.137 ppm max. in H_2O, 3918 ppm max. in sludge; dioxin: 76 ppb max. in soil, 10.6 ppb max. in H_2O, 302 ppb max. in sludge Details: Soils excavated and stored on-site prior to incineration; Two rotary kiln incinerators operating 24 hrs./day at 4 yd^3/hr.; DRE of 99.99%; Ash used as backfill with topsoil and revegetation cover; Pump and treat of shallow groundwater; GAC to treat off-gas; Treated water reinjected to aquifer; 10 yr. pump and treat	36, (1990)

B. GROUNDWATER AND SURFACE WATER				
2.b. PHYSICAL/CHEMICAL TREATMENTS: *EX SITU*				
PUMP AND TREAT IN CONJUNCTION WITH OTHER REMEDY, continued				
Land treatment of soil with incineration, and pump and treat with GAC	Present worth (7% discount rate, 30 yr. duration, ROD estimate) Total Capital O&M	$27,530,000 to $55,200,000 (1993) $12,050,000 to $20,250,000 $657,000 to 4,420,000/yr.	Montana Pole and Treating Plant Site, Butte, Montana Media: 218,000 yd^3 excavated soil; 44,000 yd^3 soil in situ; 26,500 gal. sludge; 9100 yd^3 debris; 90 mil. gal. groundwater Contaminants: max. conc.: 1160 mg/kg PCP; 2304 mg/kg PAHs; 55.6 mg/kg TPH; plus 370,000 gal. LNAPLs Details: Excavation of 208,000 yd^3 contaminated soil added to 10,000 yd^3 excavated soil stored on-site; Treatment in land treatment unit (7 yr. duration); In situ biodegradation of soils below excavation level before backfilling; Soil flushing and in situ bioremediation of inaccessible soils; Containment/hydraulic barrier installation; Pump and treat of groundwater with oil/H_2O separation, GAC, and UV oxidation; Estimated 30 yr. duration; Reinjection of treated H_2O to enhance in situ bioremediation; Decontamination and off-site disposal of debris; Excavation, transportation, incineration of sludge off-site; Long-term groundwater monitoring	37, (1993)

B. GROUNDWATER AND SURFACE WATER				
2.b. PHYSICAL/CHEMICAL TREATMENTS: *EX SITU*				
PUMP AND TREAT IN CONJUNCTION WITH OTHER REMEDY, continued				
Land treatment of soil with bioventing, chemical fixation, and pump and treat with GAC	Total O&M Capital costs: Soil remedy Groundwater remedy Debris remedy Indirect and contingency costs Present worth (ROD estimate)	$7,400,185 $1,718,402 $2,757,039 $949,776 $1,253,977 $15,551,033 (1992)	Broderick Wood Products Superfund Site, Operable Unit 2, Adams County, Colorado Media: 59,000 yd^3 organic-contaminated soil; 120 yd^3 sediments; 800 yd^3 metal-contaminated soil; 526 mil. gal. groundwater; 42,000 yd^3 sludge; 850 yd^3 debris Contaminants: up to 14,000 ppm PAHs, 8600 ppm PCPs, 0.38 ppm benzene, 21.4 ppm xylenes, and 56 ppm dioxins/furans in soil Details: 59,000 yd^3 soil and 120 yd^3 sediments excavated and biodegraded in land treatment unit; 800 yd^3 metal-contaminated soil treated by ex situ chemical fixation and disposed of in off-site permitted facility; Groundwater pumped and treated with oil/H_2O separation, clay, and GAC; Treated H_2O reinjected into shallow aquifer followed by bioventing of deep contaminants; 25 to 30 groundwater monitoring wells installed; Soil/bentonite wall plus drainage ditch linings installed; 225 tons scrap decontaminated and reclaimed off-site; Sludges reclaimed off-site; 850 yd^3 debris disposed of in permitted landfill	38, (1992, 1995)

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